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The editors of International Geology Review will give consideration to full Englis translations, condensations and reviews submitted voluntarily for publication. Translato will be appropriately credited. Original papers of international significance will also b considered for publication.

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REVIEW SECTION

NOTES ON INTERNATIONAL SCIENTIFIC MEETINGS

NATIONAL ACADEMY OF SCIENCES

OFFICE OF THE PRESIDENT
2101 CONSTITUTION AVENUE
WASHINGTON 25, D. C.

17 October 1958

Dear Dr. Howell:

The Institute is to be congratulated for embarking on such a worthwhile venture as the International Geology Review. The free and timely interchange of views and data so necessary for scientific progress will be accelerated by the Review. An essential factor in the search for truth is the opportunity for the creative thinker to consider and evaluate the thoughts of his colleagues and to have the benefit of their experience and judgment; the Review promis to enlarge greatly the opportunity for considering the full range of modern thought in this world-encompassing branch of science. The effort of searching out and disseminating stimulating literature should be amply rewarded by the bene fits that will be derived by earth scientists; progress wil be fostered throughout the entire scientific community.

I am confident the Review will immediately prove its usefulness; geologists throughout the world will surely recognize the importance of its service.

Yours sincerely,

Detlev W. Bronk

Detlev W. Bronk
President

Dr. J. V. Howell, President
American Geological Institute
2101 Constitution Avenue
Washington 25, D. C.

INTERNATIONAL GEOLOGY REVIEW

• an editorial announcement •

International Geology Review is a publication of the American Geological Institute, edited by personnel of the A.G.I. Translation Center under the editorial guidance of the A.G.I. Translation Committee. It is a monthly journal and is to be composed of approximately 90-100 pages per issue. The journal is made possible by a grant from the National Science Foundation which provides working capital.

CONTENTS

Reviews of important trends in foreign geological research and translations of outstanding reports will be published. Initial emphasis will be on the Russian literature, but, as time progresses, the editors will include reviews of research in many other countries.

Some features of the published material should be commented on. As far as possible the editorial policy is to pass on direct translations with as little "doctoring" as possible. The translation of Slavic and Oriental technical papers is extremely difficult and fraught with unsuspected hazards. When necessary, editorial or the translator's doubt as to specific meaning may be expressed by a query (?). The general character of an author's phraseology is retained as a rule in order to convey the flavor and thought process of the original. It should be emphasized that the views of the editors are not necessarily reflected in these unmodified statements.

QUALITY OF SCIENTIFIC WORK

The material presented in this and subsequent issues is considered to be of relatively high quality, reflecting current trends in research, particularly in the Soviet Union. As a rule no attempt is made to qualify or comment on specific statements or assumptions on the part of the author which may be considered by the editors to be misconceptions. Subscribers, however, are invited to comment on the published material and to that end a <u>Letters To The Editor</u> column will be established.

COVERAGE

No boundaries are visualized, and it is hoped that eventually the Review will report comprehensively on world geology.

CONTRIBUTIONS

With the interest, cooperation of the geological profession, International Geology Review can become an important fixture in geological literature. Geologists who follow the foreign literature are invited to submit reviews of current developments in overseas countries. Original manuscripts will be welcomed.

Manuscripts and editorial inquiries
may be addressed to the -

A. G. I. Translation Center
601 West 115 Street
New York 25, New York

THE AGI TRANSLATION COMMITTEE

• its inception purposes & plans •

In early 1958, the editor was invited by J. V. Howell, past President of the American Geological Institute, to form a committee to study Russian and other foreign geological literature and methods of its translation into English. The committee members were selected from various fields of geology and its branches, with representation from both industry and education. The diversified experience of the members resulted in the collection of a mass of information, dealing with the mechanical and financial aspects of translation. The results of this survey with specific recommendations for a translation program were then submitted to the Executive Committee of the American Geological Institute, and formal grant proposals were then submitted through the AGI's parent organization, the National Academy of Sciences, to the National Science Foundation. Three grants providing for a start on the AGI translation program were made by the National Science Foundation in July, 1958.

The projects approved by the N S F included the translation of two books: D. V. Nalivkin's Facies Studies; and V. V. Belousov's Fundamentals of Tectonics. These books were selected by the Translation Committee as outstanding contributions in their respective fields. Another project is the editing or translation of available Russian abstracts, which will be incorporated in AGI's GeoScience Abstracts. International Geology Review is a part of the program, and in the near future, a complete translation of Izvestiya Akadamii Nauk SSSR, beginning with the January 1958 issue, will be made available.

The N S F support also provides for the operation of the AGI Translation Center at 601 West 115 Street, New York, N. Y. The Center is responsible for the supervision of the translation program and serves as a coordinating office for translation efforts in the area of the geological sciences.

Perhaps the main function of the Translation Committee is the recommendation of material for translation. This is a difficult job, because of the huge backlog of Soviet material. Individuals and organizations are invited to submit suggestions as to publications which should be translated together with the reasons why the translation should be made. These requests will be evaluated by the AGI Translation Committee. Translated abstracts aid some in the solution of this problem. The Translation Center is now engaged in collecting and indexing translated abstracts from various government agencies.

Now that the initial projects are under way, the Committee looks to the future. There are many more recommended books to be translated, many other journals besides Izvestiya. As more funds are made available, more translations can be undertaken, and perhaps in time all world geology will be available to the English-speaking geologist.

IGR TRANSLITERATION OF RUSSIAN[1]

The AGI Translation Center has adopted he essential features of Cyrillic Translit-ration recommendec by the U. S. Depart-nent of the Interior, Board of Geographi-al Names, Washington, D. C.

Alphabet		transliteration
А	а	a
Б	б	b
В	в	v
Г	г	g
Д	д	d
Е	е	e, ye (1)
Ё	ё	ë, yë
Ж	ж	zh
З	з	z
И	и	i (2)
Й	й	y
К	к	k
Л	л	l
М	м	m
Н	н	n
О	о	o
П	п	p
Р	р	r
С	с	s
Т	т	t
У	у	u
Ф	ф	f
Х	х	kh
Ц	ц	ts
Ч	ч	ch
Ш	ш	sh
Щ	щ	shch
Ъ	ъ	" (3)
Ы	ы	y
Ь	ь	' (3)
Э	э	e
Ю	ю	yu
Я	я	ya

However, the AGI Translation Center recommends the following Modifications:

1. Ye initially, after vowels, and after . Customary usage calls for "ie" in many names, e.g., SOVIE KIEV, DNIEPER, etc.; or "ye", e.g., BYELORUSSIA, where "e" follows consonants. "e" with dieresis in Russian should be given as "yo".

2. Omitted if preceding a y, e.g., Arkhangelsky (not iy; not ii).

3. Generally omitted.

NOTE: The well-known place and personnel names that have wide acceptance in international literature will be here adopted. However, German-type transliteration e.g., J for Y will not be used.

[1] Due to the individual training and tastes of the translators and reviewers whose work is published in this issue of IGR., it has been impossible to follow the above recommended system. In the near future, however, an effort will be made to standardize transliteration procedures.

EXPLANATORY NOTES ON THE TECTONIC MAP of the USSR and ADJOINING COUNTRIES [1]

by

N. S. Shatzki and A. A. Bogdanoff

• translated by Theodore Shabad & C. Muromcew •

PREFACE

There are as yet no generally accepted conventional symbols used in small-
:ale tectonic maps, nor is there an adequate classification of tectonic forms,
specially of the major structures of the earth's crust, that might be shown on
topographic base of relative small scale. The publishers and the compilers
: the Tectonic Map of the USSR therefore thought it necessary to accompany
by a short Explanatory Note stating the principles used in working out the
onventional symbols and describing the basic features of the tectonic structure
the regions of the USSR that determine their classification in one or the other
the structural categories.

A large group of geologists took part in the compilation of the Tectonic
ap of the USSR. Some of them have rather divergent views on various ques-
ons relating to the tectonic structure of the USSR and it was not always possi-
e to reconcile these views in the course of the editorial work. The Explana-
ry Note lists the major questions relating to the regional tectonics of the
SSR that are still in dispute.

A list of the geologists who took part in
e compilation of the map appears in a
ecial insert on the map, indicating the
ctions of the USSR and adjoining coun-
ies assigned to each person. N. S. Shat-
iy was in charge of over-all editing of
e map.

Others who took part in the compilation
d in the preparation of the new tectonic
ap for publication include staff members
the Geologic Institute of the Academy of
iences of the USSR and geologists of the
l-Union Geological Scientific Research
stitute, Moscow State University, Moscow
eologic Exploration Institute, Institute of
ctic Geology and other institutions.

The principal authors of the Explanatory Note are N. S. Shatskiy and A. A. Bogdanov. Others who took part in the writing and editing of individual sections are: N. A. Belyayevskiy, V. I. Vereshchagin, N. S. Zaytsev, Yu. A. Kosygin, P. N. Kropotkin, M. V. Muratov, M. S. Nagibina, V. N. Ognev, Ye. V. Pavlovskiy, A. V. Peyve, Yu. M. Pushcharovskiy, L. I. Salop, V. N. Sobolevskaya, L. Ya. Kharitonov, N. P. Kheraskov, Yu. M. Sheynman, N. A. Shtreys and A. L. Yanshin. The other map compilers also submitted occasional data for the note. A. L. Yanshin was in charge of over-all editing of the Explanatory Note.

INTRODUCTION

The USSR has an area of more than 22 million square kilometers, occupying the eastern part of Europe and a major part of northern Asia. In this huge area, which contains a great variety of geologic structures, all major problems relating to the

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Published in Moscow in 1957 by the State
Scientific and Technical Publishing House of
Geologic and Conservation Literature. The
map was produced jointly by the Academy of
Sciences USSR, Ministry of Geology and Con-
ervation USSR and the Ministry of Higher
Education USSR.

structure and development of the earth's crust can be successfully solved.

The first synthesis of the structure of the USSR was published in 1933 by A. D. Arkhangelskiy and N. S. Shatskiy in a well known article that was widely used by many scientists in analyzing the tectonics of Asia and other continents (Leuchs, Umbgrove, Kober and others). In 1937, at the 17th International Geologic Congress in Moscow, A. D. Arkhangelskiy presented a paper on the principal features of the geologic structure and geologic history of the USSR, describing the major results of geologic work done in pre-revolutionary times and in the first twenty years of the Soviet regime. More detailed data on the geology, including the tectonics, of the USSR were published at the same time by the Academy of Sciences USSR in a large symposium edited by A. D. Arkhangelskiy.

In the nineteen years since the 17th Congress a tremendous amount of geologic work has been done in the USSR. The entire country was covered by geologic surveys at various scales. Hundreds of deep core holes were drilled to yield data on a variety of major geologic problems. Dozens of such corings shed light on the geologic structure of the vast West Siberian lowland. More than a hundred core holes reached the Precambrian basement of the Russian platform, yielding a clearer picture of its structure and relief. Geophysical surveys, carried out in conjunction with geologic work, provided data on many submerged structures throughout the country. The huge scope of geologic work done each year in the USSR makes necessary constant revision of many existing views and conclusions. Since the 17th Congress, Soviet geologists have published a number of theoretical studies, generalizing the accumulated new data. A brief explanatory note does not enable us to provide even a cursory survey of these studies, the results of which played a major role in shedding further light on the tectonics of the USSR.

Studies of the tectonics of the USSR have been continuing in the Geologic Institute of the Academy of Sciences USSR along the lines of A. D. Arkhangelskiy and N. S. Shatskiy. Some results of these studies, covering the geology and tectonics of Kazakhstan, the Urals, the Alpine zone of the southern USSR, the Russian platfor[m] and Siberia, have been published in the form of large monographs and separate articles.

The first tectonic map of the USSR a[t] the scale of 1:4,000,000, generalizing the results of these studies, was compiled in 1951 and published the following year. The map, which received wide distributio[n] in the USSR, was the collective work of staff members of the Geologic Institute o[f] the Academy of Sciences of the USSR und[er] the direction of N. S. Shatskiy, who playe[d] the leading role in the compilation.

A new tectonic map of the USSR at th[e] scale of 1:5,000,000 was compiled for the 20th International Geological Congress in 1956. Although its scale was slightly smaller, this map was more detailed than the first one. The compilers of the secon[d] map used not only newly published works but many unpublished studies of various institutions, a group of sources that had not been used in the cimpilation of the fir[st] tectonic map. Furthermore, the new edition showed intrusions of various ages and compositions. Its conventional symb[ols] were slightly changed and further refined compared with those of the 1952 map. However, the principles used to distingui[sh] and represent structures of various magn[i]tudes remained the same. It is thus possible to use this explanatory note also for reading the first edition of the tectoni[c] map of the USSR.

PRINCIPLES OF A TECTONIC REGIONAL DIVISION OF THE USSR

Areas of folding and the main principles of their distribution in the USSR and adjoining countries.

The Age of Folding.

The age of folding is the chief criteri[on] that makes it possible to distinguish tectonic units and thus to divide any area int[o] its natural geologic regions. The age of folding is determined by the time of the last intensive geosynclinal movements; more precisely, the age of folding is the time at which a folded geosynclinal regio[n] was converted into a cratonic region, i.e. the borderline between the period of geosynclinal development and the period of cratonic development of a given tectonic zone.

It has been definitely established that atons and geosynclinal systems existed the earth's crust in all epochs and eras, least since Proterozoic times. These sic tectonic units have contrasting aracteristics. Cratons are stable segents of the earth's crust with little obility, while geosynclines are unstable gments of extreme mobility. Each of ese two structural categories is marked distinct, characteristic sedimentary rmations, specific formations and series igneous rocks, distinct structural rms, specific metallogenic processes d so forth. The times at which geonclinal systems are converted into atons therefore are not arbitrarily lected, but represent natural dates in e earth's history at which pronounced anges took place in the structure of rge segments of the earth's crust. The inciple of classifying regions on the map cording to the age of folding is natural d correct, quite objective and equally nding for all geologists who might have fferent views on questions relating to e chronologic principles of the developent of the earth's crust.

Instead of using the end of geosynclinal velopment, i.e. the time at which folded osynclinal systems are converted into atons, structural regions could also be assified on the basis of the epochs in ich new geosynclinal regions and sysms arise, i.e. the start of geosynclinal velopment. Such a classification would just as natural as the preceding one. wever, our information on the end of osynclinal development of folded zones d the time of their conversion into atons is far more complete than our owledge of the origin of geosynclinal oughs and the start of geosynclinal delopment of a given area. Therefore the st method of tectonic classification was ken in preference to the second.

There is no doubt that a modern tecnic classification covering all available ta should be based on the entire history the tectonic development of folded stems — from their origin to their conrsion into cratons. However, only oroughly studied folded regions could be assified tectonically according to this ore refined principle. In view of our even and in places completely inadequate knowledge of large, geologically complex areas, this principle could hardly be used in classifying tectonic structures of all the continents or even the area of the USSR. It was therefore quite justified that for the present the tectonic classification of the Soviet Union be based on the time of conversion of geosynclinal regions into cratons.

The idea of the universal and simultaneous appearance of folded areas has found wide acceptance since publication of the classic studies of M. Bertrand and E. Suess. In the work of H. Stille these ideas found their further and ultimate development, expressed in part in the formulation of the law of folding phases relating to the epochs of revolution that covered the entire earth at definite periodic intervals.

Analysis of the structure and history of development of the area of the USSR calls for a critical reappraisal of that point of view. Serious doubts are raised by the ideas of universality and synchronization as relating not only to individual phases but even to the epochs of folding. Available facts call for categorical rejection of the idea of the extremely short duration of the catastrophic phases postulated by H. Stille as well as their universal distribution. Not only Soviet geologists but a growing number of foreign scientists have come to this conclusion.

Nor can the idea of the simultaneous occurrence of great epochs of folding be accepted. Study of Caledonian, Hercynian and Mesozoic folding shows clearly that folding took place in different ways and at various times in different parts of the earth. The duration of the epochs of folding, i.e. the process of converting a mobile zone into a craton, was at times quite long. It can even match the length of a geologic period or more. However, by comparison with the tremendous length of time of the preceding geosynclinal development and the succeeding cratonic development, the epoch of folding is of rather short duration, representing a crucial moment in the history of the given section of the earth's crust.

The following epochs of folding were distinguished in the compilation of the tectonic map of the USSR: Archean epochs, Proterozoic epochs, the epoch from the end of the Proterozoic to the start of the Cambrian

(Baikalian or Reefian epoch); the Lower Paleozoic (Caledonian) epoch, the Upper Paleozoic (Hercynian or Variscan epoch, the Mesozoic epoch, the Alpide epoch of the Cenozoic, and the Pacific-belt epoch of the Cenozoic.

The folded structures of each of these epochs (especially the older ones) outcrop on the surface in some places, and in others are submerged at great depths below a blanket of cratonic formations.

Archean and Proterozoic Folding.

Post-Reefian time constitutes only a small fraction of the period of existence of the earth's crust and an even smaller fraction of the period of existence of the earth as a planet. Post-Reefian history covers no more than one-fifth or one-sixth of the entire history of the sial; more probably the so-called pre-historic development of the earth's crust was of much greater duration than just four or five times as long as the historic, or post-Reefian, stage of evolution, which is relatively well documented in geologic records.

It is therefore quite natural that Precambrian history be regarded as a series of "orogenic cycles" of the same type as the Caledonian, Hercynian and Alpide epochs of folding. Each of these ancient folding phases probably had its characteristics related to the changeability of tectonic processes in time and to the development of the earth's crust as a whole. However we can assume that the younger Precambrian folded systems, at any rate the Algonkian, developed through stages similar or close to the stages of development of post-Reefian folded regions. For example, the Algonkian and even the Upper Archean folded formations show geosynclinal troughs filled with thick sedimentary and volcanic strata. Also in evidence are rock associations similar to those found in formations of green-stone troughs, large unconformities cutting through tectonic structures and obscuring large plutonic bodies associated with the formation of ore deposits. Further evidence is provided by easily distinguished areas of extensive post-orogenic erosion and differential uplifting, and, in general, by all features characteristic of young folded mountain systems. On the other hand, Precambrian folding displays features peculiar to it. These include especially a high degree of metamorphism that affects all formations of the Precambrian folded zones and leads to migmatization and granitization of vast areas.

Also peculiar is the morphology of the tectonic structures of the deep Precambrian, which as yet has not been sufficiently studied.

Cratonic formations of the Precambrian periods have been preserved to a much lesser extent that geosynclinal formations in folded systems of that time. This is probably explained by the limited size of the cratons of the early Precambrian and the fact that cratonic sediments are generally thinner than geosynclinal sediments and are more easily removed through erosion during subsequent uplifting of cratonic areas.

An example of ancient Proterozoic cratonic formations in the USSR is furnished by the peculiar Jotnian formation, which is in contrast to younger cratonic formations is always associated with extensive Rapakivi granite fields.

While until recently not more than three "orogenic cycles" were distinguished in the Precambrian (including the Archean and the Proterozoic), even in relatively well known areas, such as the Canadian shield or the Baltic shield, at least five to seven such cycles have now been identified in these areas. Further mapping and study of Precambrian formations will undoubtedly make it possible to refine the methodology used to identify tectonic units on the basis of age among these ancient and obscure metamorphic formations.

The oldest Precambrian folding has been combined on our map under the general heading Archean. This is of course a catch-all term covering a very long period (of billions of years) of probably many distinct foldings, whose individual epochs and stages we cannot identify at the present state of knowledge, either by the methods of tectonics or by the methods of absolute-age determination. The term Proterozoic folding, used on the map, covers the Karelian, Saksagan and

otian folding stages. More recent folding hat took place at the end of the Protero-oic and the start of the Paleozoic is overed by the term Baikalian.

Baikalian Folding.

In 1926 V. A. Obruchev identified in-ensive dislocations dating from the end f the Precambrian in Siberia and in orthern Asia in general. He also assigned the same period the origin of ancient re-Paleozoic structural forms along the hargins of the Baikal uplands, especially he Patom ridge, similar folding in the astern Sayan, in the Yenisei horst and ess clearly expressed deformations. ater, in 1935, he described these dislo-ations in greater detail, but still as dis-ocations and movements of a given age.

N. S. Shatskiy suggested in 1932 that e folding of the end of the Proterozoic nd the start of the Cambrian be called aikalian folding; he also showed for the rst time that Baikalian folding did not iffer in any respect from the Caledonian, ercynian and Alpide foldings identified arlier by E. Suess and M. Bertrand. The aikalian epoch, like the succeeding pochs, was marked not only by great rogenic movements but by the conversion f vast folded geosynclinal systems into ratonic regions, which thus passed into ew geotectonic conditions of development.

The structure of the Siberian platform, r example, underwent major changes in is period of folding. According to Shatskiy, s basement "consists of elements of vari-us ages, namely of two ancient, perhaps rchean, granite-gneissic series — the orth Siberian (Anabarskian) and the ldanian — and much younger folded ructures of the end of the Precambrian at separate and enclose the Archean ocks. The origin of these ancient series an be assigned to the end of the Archean nd the start of the Proterozoic, while the lding that welded the Siberian platform to a single whole can be assigned to the ery end of the Proterozoic or the first alf of the Cambrian (Baikalian folding). he Archean rocks outcrop in the Anabar ock and in the Aldan River basin, and e rocks of the Baikalian folds outcrop the Lake Baikal area, in western Trans-aikalia, in the Olekma River basin in the eastern part of the Eastern Sayan and in the Yenisei ridge" (Shatskiy, 1932).

In the European part of the USSR, Baikalian folding probably gave rise to the Timan formations (Timan, Kanin, Rybachiy, Kildin); the main deformations in the basement of the Pechora synclise are apparently of the same age. That is how A. M. Mazarovich understood the extent of Baikalian folding, although he sharply restricted the time of folding to the very borderline between the Proterozoic and the Cambrian.

N. S. Shatskiy recently produced indirect proof of strong regional evidence of Baikalian folding on the periphery of the Russian platform. We know that each major epoch of folding on the Russian platform corresponds to a great regional break that arose right after the epoch of folding. For example, Caledonian folding corresponds to a universal absence of the Lower Devonian and, probably in most places, even of the lower parts of the Middle Devonian; the Hercynian epoch is reflected by a great stratigraphic break covering the Upper Triassic and the Lower Liassic; the Alpide epoch also corresponds to a general uplifting of the Russian platform. In this sequence of great universal breaks, the absence of the Middle and Upper Cambrian in the Russian platform can be explained most easily by the Baikalian (Reefian or Lower Cambrian) folding, which probably gave rise to the deformations of the Timan and adjoining zones. The question is whether the same tectonic phenomenon also accounts for the absence or reduction of the Middle Cambrian in most cross sections of the Siberian platform.

It should be noted that H. Stille in 1944 proposed the name Assynt (a lake in Scotland) for the last Precambrian folding that took place just before the Cambrian and after the Upper Algonkian. He described this orogenic epoch in greater detail in 1948. However, we cannot accept the terms "Assynt folding" and "Assynt epoch", not so much because of priority for the term "Baikalian folding", but because these terms are geologically quite unjustified. In the vicinity of Loch Assynt in Scotland, Lower Cambrian sandstones rest undisturbed, though

as old as the Upper Carboniferous.

We can thus see that both in the Lower Paleozoic and at the end of the Paleozoic folding processes continued for a long time, sometimes through one and a-half or two geologic periods, and did not occur simultaneously in all folded systems. However, all Lower Paleozoic foldings have so many common features and differ so clearly from the Upper Paleozoic foldings that the two phases can be not only distinguished but even contrasted in some respects.

The tectonic map therefore shows two systems of Paleozoic folding: the older, or Lower Paleozoic, system, known as the Caledonian, and the younger, or Upper Paleozoic, system, known as the Hercynian. The lack of sufficiently precise data on the time of folding in a number of large areas makes it impossible at the present time to provide a more detailed age subdivision of Paleozoic foldings in the USSR and adjoining countries.

Thus all Lower Paleozoic foldings on the map, except the Baikalian, are shown in the color of the Caledonian formations, and all Upper Paleozoic foldings in the color of the Hercynian formations. The Caledonian color is also used to designate zones of "early consolidation" within the Hercynian folded regions, i.e. areas that behaved in the Upper Paleozoic like ancient Caledonian zones.

It should be noted that in the USSR, as incidentally in most other parts of the world, Caledonian and Hercynian formations are so closely related to one another that the former must be regarded as the precursors of the latter. This close relationship is shown especially clearly in the tectonic development of folded zones such as the Urals, where the Hercynian tectonic changes represent a direct continuation of the Caledonian. This close relationship may also explain why marginal troughs, which are so widely developed in the Hercynian, are lacking in the Caledonian. In other words, the Caledonian formations represent a phase of incomplete folding, in which the post-geosynclinal stage of development has been greatly reduced. In the Hercynian formations, on the other hand, the final stages of development are clearly expressed. These stages

transgressively, on Torridon sandstones o arkose, changing in places directly into Lewis gneisses. The Lower Cambrian anc other Paleozoic sediments of the Assynt area represent a typical cratonic formation; the age of the Torridon arkose is not definite, but probably corresponds to the Jotnian formations of the Baltic shield. If this correlation is correct, then the stratigraphic range of the unconformity between the Torridon (Jotnian) sandstone and the Cambrian sediments at any given point would be tremendous, corresponding to the entire Reefian era (Sparagmite). Therefore the Assynt unconformity cannot be regarded as adequately defined, even from H. Stille's point of view. The age or stratigraphic position of this unconformity is still indeterminate; it may have arisen either at the start of the Reefian era (in the Upper Algonkian) or within the Reefiar or even at its end, just before the start of the Cambrian.

Paleozoic Folding.

Paleozoic folding includes generally the Caledonian and Hercynian phases; however, it would be more correct to refer to the Caledonian and Hercynian as distinct complex systems of folding. Ther is increasing evidence that the Lower Paleozoic, in addition to the folding of the Ordovician and the Silurian, included other folding phases, for example the one corresponding to the Upper Cambrian which has not quite aptly been called Salairian folding. There does not seem to be any point in perpetuating this term since the Salair folded structure arose in the more recent Caledonian folding, and possibly even in the early Hercynian. The so-calle Salairian epoch had better be named East Tuvinian or East Sayanian, for the areas where dislocations of the Upper Cambrian are especially evident.

Similarly, at least two distinct epochs of folding can be distinguished in the Hercynian formations. In the folded syster of the Urals, striking N-S, folding began intensively in the Upper Carboniferous, continued through the Permian and ended in the Early Triassic. In the E-W Hercynian system of Western and Central Europe, on the other hand, the most recent deformations are at least as old as the Lower Permian, and more often at least

nclude in particular the formation of ypical marginal troughs.

Mesozoic Folding.

Most of the Western European and ome Soviet geologists do not recognize ne independent status of Mesozoic folding, e. an epoch covering the end of the Juras-ic and the Cretaceous. They regard it as ne of the phases of Alpide orogeny or as special form of Alpide development. On ne other hand, Chinese, American and nost Soviet geologists, as well as some Vestern Europeans, regard the Mesozoic olded region as one of the major indepen-nt folded zones, equivalent to the Her-ynian zone in the intensity of magmatic nd metallogenic processes.

There is no need at present to prove detail the existence of Mesozoic folding the USSR; we shall merely note that, in ldition to the age of the intrusions in the esozoic belt of the eastern USSR, the dependent status of this folded zone is upported by the following fact: the Meso-oic folded zone is separated in the west om the Siberian platform by a typical arginal trough (the Verkhoyansk trough), e development of which ended with the ccumulation of Upper Cretaceous conti-ental molasse. Let us also recall, that e opposite margin of the Mesozoic folded elt in North America (the Mackenzie iver basin, the Arctic uplands and her areas) also contains such a marginal ough, of the same age, filled with typical ediments of marginal troughs, including l-bearing molasse.

The above-mentioned differences be-veen European geologists, on the one hand, d American, Chinese and Soviet geolo-sts, on the other, can be explained by the ct that not all folded zones have an equally de distribution. The Mesozoic zone, in rticular, is an independent and clearly fined zone characteristic of the Pacific lt, but is totally lacking in the western lf of Eurasia, in the Atlantic and on the stern margins of the Americas.

Cenozoic Folding.

The tectonic map shows two regions Cenozoic folding, differing from each ner in age. The first is the Alpide folding of the Mediterranean belt, whose geosynclinal development we regard as having started right after the Hercynian orogeny and ended at the end of the Tertiary and in the Quaternary. Study of Quaternary deposits in the foothills and terraces of the Caucasus and the Himalayas shows that these Alpide structures are in the final stage of formation of marginal-trough molasse.

Of more recent origin, on the other hand, is the Cenozoic folding of the Pacific belt in the Far East of the USSR. In Kamchatka and in the Kurile Islands, this zone evidently corresponds to the stage of accumulation of thick volcanic sediments. It must be assumed that this zone has not yet reached the stage of molasse accumulation in marginal troughs since the deep depressions of the island arcs, judging by their structural position and the abundance of submarine volcanoes, can hardly be compared with marginal troughs. In other words, this zone is in a state of incomplete folding.

Distribution of Folded Regions.

The distribution of folded zones of various ages in the western part of Eurasia differs substantially from their distribution in the east, in the Pacific belt. In the west, i.e. in the Atlantic sector, Hercynian structures are widely developed. In Europe, western Asia and the eastern margins of the Americas, these structures are apparently the most common of all the post-Proterozoic folds and also the richest in granitoid intrusions. As we have already noted, the Caledonian formations represent only the initial stage of Hercynian folding. Similarly only a small area is covered by Alpide folding, which arose as a regenerated geosynclinal region within the body of Hercynian formations. The Alpide folded region of Europe and western Asia thus represents only a sort of residual geosynclinal zone within the over-all tectonic development of that part of the world.

We find quite a different history and structure in the Pacific belt, whose northeastern sector is part of the USSR. While the folds of Europe and western Asia gradually arose on ancient cratons, the structures of the Pacific belt enclose the deep depression of the ocean. This history

of this Pacific ring is well known only since the end of the Paleozoic. It differs sharply from the history of the Atlantic sector in that the age of the Pacific structures is quite different. These folded structures are predominantly Mesozoic, with associated marginal troughs and an abundance of metalliferous granites, which are missing in the Atlantic sector. The Pacific also includes a very young zone of Cenozoic folding, which has not completed its development and is still a "live" geosynclinal region. Volcanically derived sediments are now in the process of accumulating in its troughs. The history of development of the Pacific folded belt thus differs radically from that of the European and West Asian folds. This is one aspect of the asymmetry in the development of the earth that has often been pointed out by V. I. Vernadskiy.

CONVENTIONAL SYMBOLS ON THE TECTONIC MAP

It follows from the foregoing that the age of folding was used as the basis for the legend of the tectonic map: Archean and Proterozoic folding is shown in red shading, Baikalian folding in orange shading, Caledonian folding in purple shading, Hercynian folding in brown, Mesozoic folding in green and blue, and Alpide and Cenozoic folding of the Pacific belt in two kinds of yellow.

Structural forms of folded and cratonic regions are shown by various types of cross-hatchings on the given color of the age of folding as well as by appropriate symbols. Let us now examine these in greater detail.

Structural Phases and Stages of Development of Cratons and Geosynclinal Regions

Cratons always represent features that arose in place of earlier geosynclinal regions. One of the characteristics of cratons is therefore the presence of two structural stages in their cross section: the folded basement and the cratonic blanket. The lower stage, or basement, consists of sedimentary and volcanic formations of the geosynclinal type; it is pierced by intrusions; and its rocks have been subjected to folding and metamorphism. The time of formation of the basement rocks corresponds to the pre-cratonic, or geosynclinal, stage of development. The upper stage, or cratonic blanket, consists of formations of the cratonic type, among which sedimentary rocks greatly predominate; magmatic formations generally play a subordinate role or are restricted to specific types that differ from the magmat rocks of geosynclinal regions (alkaline intrusions, basaltic flows and so forth). The rocks of the sedimentary blanket have as a rule not been subjected to metamorphism and have been disturbed only by dislocations of a cratonic type. The cratonic blanket usually is separated from the basement by a major regional unconformit

The long history of geosynclinal regions is generally characterized by inherited development. Their cross-section therefore lack such sharply distinguished structural stages as the basement and blanket of cratons. However, close analysis of the structure and history of development of geosynclinal regions also uncovers a series of clearly defined structural phases; each of these phases, corresponding to a given stage of development of the geosynclinal region, consists of a group of formations that is often separated from those above and below by regional unconformities. Deep-seated (lower) structural phases are usually dominated by volcanically derived and sedimentary formations (of the spilite-keratophyre type and others corresponding to early stages of geosynclinal development. The middle structural phases often contain carbonates, shales and graywacke formations, pierced by granitoid intrusions. Upper structural phases contain flysch, molasses, coal-bearing basins and other formations.

The upper structural phases are generally formed in separate troughs in the final stages of geosynclinal development, when the earlier dominant downwarping changes into uplifting and mountai building begins.

Intrusive Masses.

Intrusive masses are of great importance within folded regions. They often form large bodies and always occupy a definite structural position. These masse are generally not shown on tectonic maps because it is assumed that they may obscure the clarity of representation of the folded structures. However, in view of the

reat theoretical and practical importance f showing both tectonic structures and ntrusions, we have attempted to represent oth on the new tectonic map of the USSR.

The magmatism of geosynclinal regions s too complex and has not been adequately tudied to enable us to draw general con- lusions about the sequence of intrusive nd extrusive activities in various types of ocks. Study of a number of geosynclines as led to the opinion that active downfold- ng stages correspond to the formation of ltrabasic and gabbro intrusions and their cid derivatives (sodium and sometimes otassium granitoids), which are probably aragenetically related to the formation of pilite-keratophyre extrusions. The final tages of geosynclinal development, ac- ording to this view, corresponds to the ntrusion of granites and related rocks, hile the post-geosynclinal and cratonic tages correspond to the intrusion of ultra lkaline magmas. The huge amount of ata gathered for the territory of the USSR hows, however, that such a magmatic equence is typical only of certain types f geosynclinal troughs.

In some cases even adjoining troughs f the same geosynclinal system display totally different course of magmatic evelopment. For example, the Tagil geo- ynclinal trough of the Urals displays ltrabasics, gabbro and plagioclase granite ntrusions with no normal granites what- oever; in this case, the nephelite-syenites re derived from basic magma and do not epresent so-called post-orogenic intru- ions characteristic of the cratonic stage f development. In the adjoining Urals- obol uplift, on the other hand, there are uge masses of normal granites in addition o the ultrabasics and gabbro. Finally, the ilair geosynclinal trough of the Urals con- ains only ultrabasics in association with ome small gabbro bodies. On the other and, vast areas of the Verkhoyansk geo- ynclinal region contain granites and ranodiorites but no ultrabasics or gabbro.

Furthermore, we must also consider e possibility and probability of the occur- ence of pseudomagmatic bodies of various orms with metamorphic and metasomatic rocesses in sedimentary and volcanic ocks, some parts of which may then take n the appearance of ultrabasic, basic and acidic masses. Such new formations may be especially common in heavily metamorphosed Precambrian rocks.

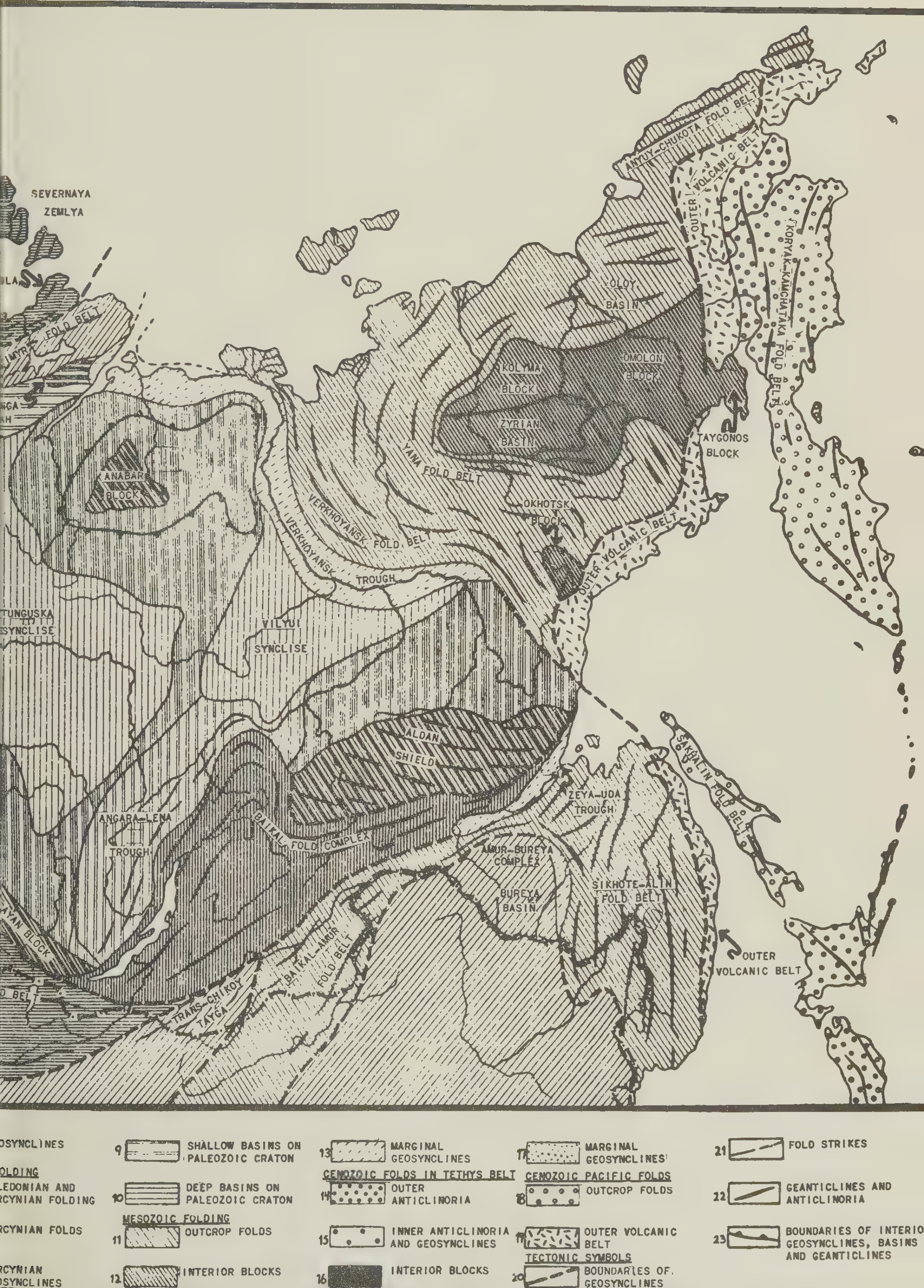
The representation of intrusions on tectonic maps raises a number of complex problems that can not always be solved satisfactorily. The main difficulty lies in determining the tectonic position of intrusions, i.e. establishing their form (batholith, laccolith, stock and so forth) and their relationship to the tectonic processes that formed the folded host structure. If these data were available for every intrusion, each mass might be shown on the map by means of a cross section taken at a certain depth, which would be free of the influence of the relief and would reflect more exactly the general morphology of the plutonic body. Such a representation of intrusions would undoubtedly have improved the map.

However, the intrusions in the various folded zones of the USSR have not yet been studied in sufficient detail and objectivity for this purpose. Therefore the tectonic map shows intrusions as they would be shown on a geologic map, that is, as exposed by erosion, and without defining the structural or genetic type of the plutonic bodies, but classifying them as ultrabasic and gabbro, granites and granitoids, and alkaline rocks. The sequence of formation of intrusions can be deduced from their position in the various structural stages of the geosynclinal regions. For most intrusions, moreover, their age is given by a figure placed next to the Greek letter that indicates their composition.

This classification of intrusions is carried through for all folding stages, except the Archean, which cannot be so classified at present. The classification does not apply to ancient formations that make up the cores of anticlinoria in areas of Paleozoic and later folding.

Trap rock intrusions on the margins of the Tunguska syncline of the Siberian platform occupy a very special position. These tabular bodies are very unusual. On the one hand, they are closely related to dikes and central conduits, and, on the other hand, to extrusions. The unusually complex structure of this magmatically derived formation has forced us for now to limit ourselves to showing only the zones of trap-rock


TECTONIC SCHEME OF THE USSR
FROM
"A TECTONIC MAP OF THE USSR AND
ADJOINING COUNTRIES"
SCALE: 1:5,000,000 1956
POLISH-LITHUANIAN SYNCLISE
CARPATHIAN TROUGH
VISTULA TROUGH
BREST TROUGH
BALTIC SYNCLISE
BALTIC SHIELD
NOVAYA ZEM
FOLD BELT
CARPATHIAN MTS
BYELORUSSIAN ANTICLISE
PRIPET TROUGH (PRIPYAT)
UKRAINE SHIELD
UKRAINE SYNCLISE
MOSCOW SYNCLISE
TIMAN UPLIFT
PECHORA SYNCLISE
VORONEZH ANTICLISE
PACHELMA TROUGH
DOBRUDJA
GLASOV SYNCLISE
URAL TROUGH
URAL FOLD BELT
OB-TAZ
SYNCLISE
DONETS BASIN
VOLGA-URALS ANTI-CLISE
CRIMEA
PRE-CAUCASUS DEPRESSION
NORTH CASPIAN SYNCLISE
IRTYSH SYNCLISE
RION BASIN
LESSER CAUCASUS FOLD BELT
CAUCASUS FOLD BELT
TURGAI TROUGH
TOM-KOLY
FOLD BEL
NORTH UST-URT TROUGH
WEST CENTRAL KAZAKHSTAN FOLD BELT
SALAIR
KURA BASIN
CHUY BASIN
EAST CENTRAL KAZAKHSTAN FOLD BELT
ALTAI FOLD
NORTH KYZYL-KUM SYNCLISE
KOPET-DAG FOREDEEP
KOPET-DAG
0 200 400 600 800 1000 KM
PAMIR TROUGH
N. TIEN-SHAN
S. TIEN-SHAN FOLD BELT
PAMIR FOLD BELT
PRECAMB
1
2
3
4


SEVERNAYA ZEMLYA
ANYUY-CHUKOTA FOLD BELT
OUTER VOLCANIC BELT
KORYAK-KAMCHATKA FOLD BELT
OLOY BASIN
KOLYMA BLOCK
OMOLON BLOCK
ZYRIAN BASIN
TAYGONOS BLOCK
YANA FOLD BELT
OKHOTSK BLOCK
ANABAR BLOCK
VERKHOYANSK FOLD BELT
VERKHOYANSK TROUGH
OUTER VOLCANIC BELT
TUNGUSKA SYNCLISE
VILYUI SYNCLISE
ALDAN SHIELD
SAKHALIN FOLD BELT
ZEYA-UDA TROUGH
ANGARA-LENA TROUGH
BAIKAL FOLD COMPLEX
AMUR-BUREYA COMPLEX
SIKHOTE-ALIN FOLD BELT
BUREYA BASIN
OUTER VOLCANIC BELT
BAIKAL-AMUR FOLD BELT
TRANS-CHIKOY TAYGA
9 SHALLOW BASINS ON PALEOZOIC CRATON
10 DEEP BASINS ON PALEOZOIC CRATON
MESOZOIC FOLDING
11 OUTCROP FOLDS
12 INTERIOR BLOCKS
13 MARGINAL GEOSYNCLINES
CENOZOIC FOLDS IN TETHYS BELT
14 OUTER ANTICLINORIA
15 INNER ANTICLINORIA AND GEOSYNCLINES
16 INTERIOR BLOCKS
17 MARGINAL GEOSYNCLINES
CENOZOIC PACIFIC FOLDS
18 OUTCROP FOLDS
19 OUTER VOLCANIC BELT
TECTONIC SYMBOLS
20 BOUNDARIES OF GEOSYNCLINES
21 FOLD STRIKES
22 GEANTICLINES AND ANTICLINORIA
23 BOUNDARIES OF INTERIO GEOSYNCLINES, BASINS AND GEANTICLINES

concentration, thus indicating the basic distribution of the intrusions.

Structural Elements of Cratons and Folded Regions.

The main structural elements in folded regions are anticlinoria and synclinoria, which are often grouped in anticlinal and synclinal zones. Detailed study of some areas has shown that synclinoria arise in place of former geosynclinal troughs, and anticlinoria in place of former geanticlinal uplifts.

We apply the term anticlinoria to quite large and complex folded structures, whose cores consist of the rocks of lower structural stages and which are generally characterized by a long period of usually inherited development. We apply the term synclinoria to large and complex synclinal downwarps, filled with the folded rocks of upper structural stages.

Some geosynclinal regions (such as the Alpide zone of Turkey and the Mesozoic zone of northeastern Siberia) contain rigid blocks dating from an older folding stage. Sediments of the same age as the geosynclinal formations of surrounding areas either are totally absent in these rigid blocks or are represented by a thin blanket of slightly dislocated rocks. The folded structures of a geosynclinal region often "adapt" themselves to the contours of these older blocks, seemingly flowing around them, branching out at their corners and so forth. The strike of the newer structures of the geosynclinal region need not be parallel to that of the older structures within the rigid block.

Such older blocks within geosynclinal regions, for example the Kolyma and Galata blocks, are known as "inner blocks."

These blocks may be of various origins. The blocks in the western part of Central Kazakhstan (the Kokchetau and Ulutau blocks) were quite properly regarded by A. D. Arkhangelskiy as areas of earlier consolidation within a once unified Paleozoic geosynclinal region. These blocks are distinguished by the fact that they have a well defined western border and an indefinite eastern margin, which is to say they are "un'hemmed." These blocks are deeply penetrated by troughs filled with an Upper Paleozoic geosynclinal series of formations, the very character of which changes gradually within the blocks. Under these conditions the eastern border of this "zone of ancient consolidation" in Central Kazakhstan can be shown only approximately. Other inner blocks are probably remains of ancient folded areas that remained undisturbed by the movements and magmatism of later folding. The Kolyma and Galata blocks probably belong to this category.

Geosynclinal regions also contain depressions that are usually filled with molasse or related formations (sometimes even salt-bearing). These interiordepressions were formed in the final stages of geosynclinal development. Their sediments usually form gentle brachiofolds. Intrusions usually take the form of basic dikes and, in rare cases, small granitoid bodies. Along the margins of the depressions, one often finds volcanic flows related to fissures in the earth's crust.

Intermontane (interior) depressions containing this type of rocks developed in Mesozoic and Cenozoic times over large areas of Central Asia on top of an older Paleozoic or even Precambrian folded basement in connection with new orogenic movements.

Cratonic regions with a folded basement dating from the Palezoic or earlier contain tectonic structures of various magnitudes.

The cratonic structures of the first order are: shields and platforms, anticlises and synclises. Shields are outcrops of the basement that have been subjected to erosion during most of the period of development of the craton; for example, the Baltic and Aldan shields. Platforms, on the other hand, are regions that have been subsiding over a long period of time and have accumulated thick sediments. Both shields and platforms are distinctive structural forms of the earth's crust that are separated from each other by well defined flexure folds. The same type of flexures and ridge-like formations separate platforms of different degrees of submergence. Precambrian outcrops that are too small to be termed shields are called blocks, such as the Anabar block.

Synclises[2] are depressions in the sur- ace of the basement that have developed ver a long period and have been filled ith a thick cratonic cover up to 3 or 4 ilometers deep, in some places even 7 to kilometers (Vilyui synclise) or as much s 10 kilometers or more (Caspian syn- lise). Anticlises are uplifts that repre- ent residual structural forms between ynclises; they are usually covered with relatively thin cratonic mantle.

The configuration and the principal haracteristics of the structure of these tructural elements of cratons are re- ected by data on the form and the depth f the basement surface. Within the USSR ese data can be generalized with a cer- in degree of accuracy for various cratons or the Russian platform, except for the ore deeply submerged southeast and outhwest sections, we have adequate data represent the relief of the basement urface by means of structure contours. ithin the West Siberian platform, the asement surface can be shown only hy- othetically by means of structure con- ours. In the case of the Turgai platform, e lack the data necessary to reconstruct e depths of the folded Paleozoic base- ent. The structure of the Siberian plat- rm can be established only by analyzing e thicknesses of a certain part of the ross section of the cratonic mantle (the esozoic in the Vilyui synclise, the iddle and Upper Paleozoic and the Lower esozoic in the Tunguska syncline, and e Lower Paleozoic on the slopes of the nabar block and the Aldan shield). It is course difficult to correlate these data r various parts of the Siberian platform, it they do supply a general picture of the ructure.

Aside from anticlises, cratons con- in rather large positive structures that ther represent complex anticlinal crests s in the Tokmovo and Olenek structures have not yet been clearly identified (for ample, the Turukhansk structure). On e map these structures are designated the neutral term "uplift." Similarly, addition to synclises, cratons contain her large negative structures differing from the synclises. These structures are also designated by neutral terms, such as "depressions" and "troughs".

Some cratons contain a special kind of anticlise in the form of a transverse uplift separating adjoining depressions. This structure is called a saddle, as the Latvian and Kustanay saddles.

Second-order structures include many of the aforementioned depressions, troughs and uplifts. In addition, the Russian platform includes ridges that represent usually a chain of placanticlines formed along the main tectonic seams of the crystalline basement.

Structures of even higher orders include placanticlines, domes, flexures and various forms of salt tectonics.

In addition to the above-mentioned tectonic structures, various fault fractures are of considerable importance in many places. These displacements are all indicated by means of the same symbol because they still cannot be classified by types at this stage.

Marginal Structures of Cratons and Folded (Geosynclinal) Regions.

Of great importance in the history of the earth's crust is the problem of the relationships in time and in space between cratons and surrounding geosynclinal regions. It has been established that as a rule cratons are separated from surrounding geosynclinal zones by deep-seated tectonic seams, for which the term "marginal seams" has been proposed. An example is the flexure in the crystalline basement of the Baltic shield along the zone of Caledonian folding; also the deep fractures along the Eastern Sayans separating Caledonian folding on their southwestern slopes from cratonic formations of the same age on the northeastern slopes. As N. S. Shatskiy has shown, the marginal seams represent very complex structural zones of deep-seated fractures that have developed over a long period. Movements along these fractures have been especially pronounced during the time of development of the geosynclinal system and during times of folding, but have often occurred later, during the cratonic stage of development of the given segment of the earth's crust.

ienerally equivalent to the "Autogeosyncline" f Kay's terminology.

If the geosynclinal system is bounded by a structurally higher section of an older craton, then the boundary between them usually remains distinct during a period of folding and toward the end of the geosynclinal conditions. In that case the marginal seam is evident on the surface and can be mapped. Very often the folded system is overthrust toward the craton along the marginal seam.

In most cases, however, the geosynclinal system is bounded by more or less submerged sections of cratons. In that case, marginal troughs are formed along the border during the final stages of the geosynclinal system and its transformation into a mountain system. These marginal troughs usually occur on the outer margins of the cratons, but sometimes also on the margins of the geosynclinal system, so that we can distinguish two different types of structures: in some cases, domes and block faulting, and in other cases, linear folding. Marginal troughs are always asymmetrical; viewed from above, they often appear as a system of chain-like depressions filled with specific types of sediments (parallitic coal-bearing formations, molasse or salt-bearing formations). As a rule no magmatic activity is evident within the troughs. In the case of many troughs, a gradual migration of their axis toward the craton has been established.

Transverse troughs that penetrate deeply into cratons are an unusual and very important form of marginal troughs. The depressions of the Donets and Kuznetsk basins might serve as examples. Transverse troughs are formed at the same time as marginal troughs, i.e. during a period of folding and mountain formation in an adjoining geosynclinal system, but instead of lying along the edge of the craton, the transverse troughs are placed at right angle or obliquely to the craton margin. Transverse troughs are found only at the apexes of re-entrant angles of cratons. Similar troughs are sometimes found at apexes of re-entrant angles of individual platforms within the cratonic region, as in the case of the Pachelma trough.

The above-mentioned types of tectonic structures are designated on the map by various hachures and colors. In some cases their character is emphasized by appropriate inscriptions.

PRINCIPAL FEATURES OF THE TECTONIC STRUCTURE OF THE TERRITORY OF THE USSR

The USSR includes folded regions of various ages. The European part of the USSR includes most of the Precambrian Russian platform. The Central part of Siberia also consists of the Precambrian Siberian platform. Vast areas of Western Siberia, the Turan lowland, the mountain systems of the Urals, Central Asia and southern Siberia, as well as the Taimyr and the islands of Severhaya Zemlya are regions of Paleozoic folding. Paleozoic folded systems that have been submerged to great depths and are covered by a cratonic mantle of the Mesozoic and Cenozoic enclose the Russian platform on the south and southwest. Caledonian and Hercynian zones can be distinguished with varying degrees of clarity within the regions of Paleozoic folding. The Alpide folded zone, whose margins penetrate into the southwestern part of the USSR, includes the mountain systems of the Carpathians, the Crimea, the Caucasus, the Kopet-Dag, the Pamirs, and the intervening depressions and deep troughs of the Black Sea and the southern Caspian. In the eastern part of the USSR the vast areas of the Verkhoyansk Kolyma region, Chukotka, the Mongolian-Okhotsk belt and the Maritime region belong to the period of Mesozoic (Yenshan) folding. Finally, Kamchatka, the Kurile Islands, Sakhalin and a large part of the Sea of Okhotsk belong to the period of Cenozoic folding, different both in time and in degree of completion of the geosynclinal development from the Alpide zone in the south and southwest of the USSR.

Russian Craton

The Russian craton, also known in the literature as the Russian platform (E. Suess), the East European craton (A. D. Arkhangelskiy) and Fenno-Sarmatia (H. Stille), occupies a large part of the European USSR and the Scandinavian peninsula. Its borders are: in the northwest along the foot of the Norwegian Caledonian zone, in the northeast along Novaya Zemlya and the Pay-Khoy, in the east along the western

lopes of the Urals. In the south the border f the craton cuts across the northern part f the Caspian Sea and then proceeds from he Volga delta toward the Donets Basin. There it makes a sharp angle and, skirting he eastern part of the Ukrainian shield, runs west across the northern part of the Sea of Azov and the Perekop Isthmus toward he Danube lowland. Then the border turns northwestward and runs along the eastern Carpathians, along the Vistula and in a straight line toward Denmark.

One of the Principal features of the outline of the Russian platform is the fact hat over considerable distances its borders run in straight lines, sometimes ,500 to 2,500 kilometers long. Another feature is its sharp angularity. Its northwestern and southwestern borders, for xample, meet at right angle in the North ea. Its northeastern extremity, in the astern part of Bolshezemelskaya Tundra, s also close to a right angle. The southastern margin also has a rectangular, hough somewhat smoother form.

The folded basement of the craton is ot homgeneous in composition and age. It utcrops widely within the Scandinavian eninsula, Finland, Karelia and the Kola Peninsula (Baltic shield), in the Timan and he Kanin peninsula, in the southwestern art of the Ukraine (the Ukrainian shield) nd forms small outcrops in the Don alley near Pavlovsk and Boguchar (in he Voronezh anticlise). Over the rest of he craton, the basement is submerged to arying depths, in some places of coniderable magnitude, under a mantle of ratonic formations and has been reached nly by deep borings.

In the northeastern part of the craton in the Kanin peninsula, the Timan and the Bolshezemelskaya Tundra), the basement onsists of a thick series of seicitic and hloritic schists, intruded by small granioid masses. The age of this series is Reefian, and possibly Cambrian in part. The time of completion of folding in this rea is assigned to the Baikalian epoch. Other folded structure of the same age are he Varanger and Rybachiy peninsulas and Kil'din Island, which consist of dislocated ediments of the Hyperborean formation Sparagmite and Reefian series). The remaining larger part of the craton has a basement consisting of Proterozoic and Archean folded rocks.

The Baltic shield contains a number of folded structures striking generally northwest. They are, going from northeast to southwest: the Kola folded zone, consisting chiefly of Proterozoic folds; the Belomorsk block, consisting of Lower Archean gneiss series that have been granitized by Lower and Upper Archean granites; the complex folded system of the Karelian zone, which contains several large Proterozoic anticlinoria and synclinoria; the Finnish folded zone, consisting also of Archean and Proterozoic series; and finally the West Finnish block, which like the Belormorsk block consists mainly of Archean formations. In the northern part of Scandinavia the Karelian and Finnish zones pass into the Lapland zone, where the strike changes to north-south.

The Archean rocks that form the cores of folds and ancient blocks in all these systems consist mainly of granitized gneisses. Two structural stages can be distinguished among the upper formations. The lower one consists of Upper Archean iron-bearing strata and Lower Proterozoic spilite-keratophyre and schist formations of the Karelian and Kola zones. The rocks that make up this structural stage are heavily dislocated and granitized. In the West Karelian and Central Kola anticlinoria, these rocks are overlain unconformably by non-granitized and slightly dislocated Upper Proterozoic rocks of the Segozero and Onega series, which here make up the second structural stage. In the East Karelian synclinorium, the bottom of the Upper Proterozoic (quartzites and diabases of the Segozero series) has been dislocated together with the older beds. Here the second structural stage consist of land-derived and extrusive rocks, marbles and Shungite schists of the Upper Proterozoic (Onega series), intruded by diabase sills. These rocks are non-granitized and dip relatively gently.

The eroded surface of the folded geosynclinal formations and the intrusive bodies is overlain by Jotnian sediments, which are structurally of the cratonic type (Shoksha sandstones and others). The time of their formation coincides to certain extent with the intrusions of alkaline

Rapakivi granites of the Vyborg and other blocks.

The Ukrainian shield, which has an unusually widespread development of granitoids and granitized rocks of the Archean and, in part, the Lower Proterozoic, clearly displays synclinal folds of the Krivoy Rog series (the so-called Saksagan folds) striking north-south.

Systems of Saksagan folds striking north and northwest are also found in the Voronezh anticlise around Kursk and Staryy Oskol. The connection between the Karelian folding of the Baltic shield and the Saksagan folding of the southern part of the craton is still not clear. It is quite possible that the latter is older than the former. This is indicated by the absolute age of the rocks of the Krivog Rog series (Upper Archean) and the intersection, shown by magnetometric surveys, between the Saksagan northerly strikes and the Karelian northeasterly and easterly strikes in the central parts of the platform.

The relief of the surface of the folded basement of the Russian craton, which controls the structure of the cratonic mantle, is quite complex. As noted above, the larger Baltic shield in the north and the smaller Ukrainian shield in the south are virtually devoid of any sedimentary cover. The principal positive structures in that part of the craton which is covered by a sedimentary mantle are the Byelorussian, Voronezh and Volga-Urals anticlises and the Timan uplift. (The designation of the Timan as an anticlise on the map is an error that was discovered too late for correction. In its history of development and morphology the Timan differs markedly from the true anticlises. The same is true of the Anabar and Yenisei "anticlises.")

The Byelorussian and Voronezh anticlises form a system of gentle uplifts of the basement striking northwest from the lower Don to eastern Poland. The anticlise crests are at a depth of only a few hundred meters, and even outcrop in some places near the Don River. The crests of these anticlises are covered with a thin mantle of Middle and Upper Devonian sediments, transgressively overlain in some places by Upper Jurassic and Upper Cretaceous rocks.

The Voronezh and Byelorussian anticlises are separated from the Ukrainian shield by the deep trough of the Greater Donets Basin, and by its western continuations, the Pripet and Brest troughs. Befor the Lower Devonian, the area of these troughs was occupied by the single Sarmatian shield, which was equivalent in size to the Baltic shield. About the time of the Middle Devonian, a system of large fractures apparently developed along the crest of the Sarmatian shield, leading to the subsidence of the system of depression of the Greater Donets Basin trough. This long, complex process, which was associated in the Upper Devonian with active volcanism around Chernigov and along the southern margin of the Donets Basin, led to the accumulation in the trough of thick Middle and Upper Paleozoic sediments, including widespread salt-bearing formations in the Upper Devonian. In subsequent epochs, the central part of the trough expanded at the expense of slopes of adjoinin uplifts and became the Ukrainian synclise, filled with thick Mesozoic and Paleocene sediments. In the central parts of the Greater Donets Basin trough, the folded basement is at a depth of 3 to 5 kilometers The slopes of the trough are complicated by a system of faults in echelon. The trough contains many indications of salt tectonics. Salt domes, with Upper Devonia salt cores, form two systems of uplifts parallel to the margins of the basement. In the southeast, the folds of the Donets Basin penetrate into the Greater Donets Basin trough (see below).

The Volga-Urals anticlise is noted for its very complex structure. It contains a system of individual uplifts and depressions, many of which differ in age.

In the northwest the anticlise contains the large Tokmovo uplift, in whose crest Precambrian crystalline rocks lie at depth of about one kilometer. The eastern and southern parts of the anticline contain a system of ridges (the Vyatka, Kama and Zhiguli ridges) and troughs of various ages (the Ulyanovsk-Saratov trough dating from the Mesozoic and the Melekess trough dating from the Paleozoic). The ridges are complicated by placanticlines, such as those of Tuymazy and Ufa, and by flexures, such as the one of Buguruslan. In the area of these uplifts the basement

lies at depths of the order of 1,600 to 1,800 meters, and in the Melekess trough it lies at 2,500 meters.

In the Volga-Urals anticlise the cratonic mantle consists of sediments from the Middle Devonian to the Upper Permian. Depressions contain Lower Triassic sediments, as well as Jurassic and Cretaceous rocks, as at Ulyanovsk. By now the structure of the anticlise has been studied quite fully. It is one of the great oil-bearing regions of the Russian platform, whose oil deposits are associated with Devonian sediments.

The southeastern corner of the craton is occupied by the Caspian synclise. Within this structure the folded basement is submerged at great depths, exceeding 10 kilometers according to geophysical surveys. In the east the synclise merges with the southern part of the Urals marginal trough (see below). The boundary between these two structures cannot be exactly defined except for the linear position of salt structures characteristic of the marginal trough.

The northern limb of the synclise consists of a system of flexures arranged around the Caspian en echelon, including the Tokarevka and Buzuluk flexures, which separate the synclise from the Volga-Urals anticlise. In the west the Caspian synclise is bounded by the dislocations of the Don-Medveditsa ridge, which in turn complicate the structure of the eastern limb of the Voronezh anticlise. This is a system of box-like placanticlines consisting of Devonian and Carboniferous limestones and overlain by slightly disturbed Jurassic, Cretaceous and Paleocene rocks. The Don-Medveditsa ridge is separated from the Caspian synclise by the large Stalingrad flexure, which is continued in the south by the eastern scarp of the Yergeni. The flexures surrounding the Caspian synclise are dislocations that developed over a long period of time in the Paleozoic, Mesozoic and Cenozoic eras. They constitute a distinct controlling factor for the distribution and thickness of the sediments that fill the synclise. North of Stalingrad, for example, the Stalingrad flexure marks the western limit of Permian and Triassic sediments.

An east-west belt of positive gravitational anomalies has long been known to exist on the southeastern margin of the Caspian synclise, just north of the Ustyurt. It was once thought that this belt was related to the existence of buried folded structures connecting the Urals with the Donets Basin. Borings have now established that the gravitational maximum corresponds to a buried cratonic uplift, in whose crest Jurassic rocks rest directly on Upper and Middle Carboniferous limestones. This uplift has been named the South Emba placanticline. Judging from geophysical data, its crest is fractured over a great distance. On its southern limb, some Carboniferous beds consist of coarse clastic rocks that may already be part of the molasse formation of the Hercynian marginal trough situated farther south. Mesozoic and Tertiary sediments on top of the South Emba placanticline do not form an inherited structure and dip undisturbed southward under the Ustyurt. In view of all these data, the boundary of the Caspian synclise and of the Russian craton is drawn on the map along the fracture in the crest of the South Emba placanticline and then west-northwest, passing north of Astrakhan, where borings through flat-lying jurassic rocks have reached dislocated Lower Permian sediments of the same age and composition as the sediments in the Urals marginal trough around Aktyubinsk and Chkalov (now Orenburg).

Typical of the central parts of the Caspian synclise is the widespread occurrence of salt domes with Permian salt cores. It is quite possible that salt-bearing beds of various ages are also found farther west in the synclise in the structure of certain large and complex domes, such as the ones of Baskunchak, Inder and Chelkar. Upper Devonian salt-bearing facies may extend into the Caspian synclise from the Donets trough. It is also possible that salt-bearing beds may be found in the Upper Carboniferous since its sediments in areas adjoining to the north contain anhydrite beds and, according to core sampling at Buzuluk, even salt.

Various geophysical data suggest that the Caspian synclise contains several buried uplifts of the crystalline basement that affect the morphology of the salt

domes but influence only slightly or not at all the distribution of facies and thicknesses of the Middle Jurassic and more recent sediments. Using seismic and gravimetric data, we have shown the probable internal structure of part of the Caspian synclise by means of contours corresponding to the depth of the bottom of the salt-bearing formations. The deepest troughs of the synclise must be filled with extremely thick Permian, Triassic and probably Lower Jurassic sediments, measuring 6 to 7 kilometers.

The northern part of the Russian craton contains the large Moscow synclise. It is bordered in the northwest by the Baltic shield, in the southwest and south by the Byelorussian, Voronezh and Volga-Urals Anticlises, merges in the east with the Glazov synclise, and is bordered in the northeast by the Timan uplift. In the central parts of the synclise the Precambrian crystalline basement lies at a depth of about 2,500 meters. The limbs of the synclise vary in structure. The southwest limb, facing the Voronezh anticlise, is complicated by gentle flexures; the average dip of the limb does not exceed 1.5 to 2 meters per kilometer. The southeast limb is apparently complicated by a series of ridge-like uplifts and placanticlines; the northwest limb is a vast monocline (the average dip of the surface of the basement here is 2 to 3 meters per kilometer). The structure of the northeast limb is still not adequately known. It is possible that a deep depression along the Timan overlies the zone where the Karelian and Reefian folding systems are assumed to meet. Some evidence for this assumption is provided by information, which is not entirely confirmed, concerning the existence of salt domes north of Syktyvkar (the Seregovo domes). The inner sections of the Moscow synclise are complicated by a system of placanticlines of the Sukhona ridge, such as the Soligalich placanticline, striking from the southwest to the northeast along the axis of the ridge.

The Moscow synclise is an ancient depression of the Russian craton that existed as a huge trough as early as Reefian and Lower Paleozoic times. It contains a full stratigraphic cross section of the cratonic mantle, from the Reefian formations to the Upper Cretaceous.

The Moscow and Caspian synclise are joined by the narrow but rather deep Pachelma trough. This large graben-like depression opens both to the northwest and to the southeast. It was formed actively as early as the Reefian and Caledonian stages of cratonic development and was filled at that time by sandstones and shales more than 1,000 meters thick. At that time the Pachelma trough separated the Sarmatian shield from another large ancient shield that occupied the area of the present Volga-Urals anticlise. There is only slight evidence of movements in the Pachelma trough during the Devonian and Carboniferous periods, but active subsidence was renewed in the Upper Jurassic, opening a wide strait for marine transgressions. Along the axial part of the Pachelma trough the basement of the craton lies at a depth of 2,000 to 2,500 meters. Its northeast slope is complicated by a system of dislocations of the Kerensk-Chembar ridge, which continues toward the northwest in the large Oka-Tsna ridge, bordering the Tokmovo uplift of the Volga-Urals anticlise on the northwest.

The Glazov synclise is separated from the Moscow synclise by the gentle uplift of the Vyatka ridge. The Glazov synclise is a flat and rather deep depression (the depth of the basement varies here from 2,200 to 2,700 meters), merging in the east with the Urals marginal trough. The depression is filled with thick Middle and Upper Paleozoic limestones and land-derived sediments among which Permian rocks predominate.

The Timan uplift differs in many respects from the typical anticlises of the Russian craton. It consists of a number of elongated cratonic folds striking northwest and complicated by longitudinal faulting. These folds are made up of cratonic formations dating from the Carboniferous and the Upper and Middle Devonian. The cores of the largest anticlises consist of folded Reefian and possibly also Cambian rocks. The limbs of the folds dip rather sharply, but their crests are flattened. The clearly expressed linear character of the structural elements of the Timan reflects the strike of Reefian folding, which gave rise to the Timan, and is possibly related to the relative youth of the basement in this section of the craton, and hence to its great tectonic activity and its ability to submit to folding.

The extreme northeastern corner of the Russian craton, occupying the greater part of the Bolshezemelskaya Tundra, forms a huge depression known as the Pechora syncline. The structure of this territory, which is covered completely by a mantle of unconsolidated sediments, is still not well known. We can only say with certainty that its basement consists of Reefian folded formations and that its cross section displays a full and rather thick series of Paleozoic and Mesozoic rocks, with predominating marine epicontinental sediments. The Pechora synclise is bordered in the east by the deep depression of the northern part of the Hercynian Urals marginal trough. In its center, the synclise contains a zone of dome-like uplifts, striking northwest (the Pechora ridge). The crest sections of these domes contain Devonian rocks at relatively little depth.

The southwestern margin of the Russian craton, a large part of which lies in Poland, consists of the limbs of the Ukrainian shield and the Byelorussian anticlise, whose Precambrian basement is submerged to a depth of 2,000 to 2,500 meters. This limb contains two large depressions (the Baltic and the Polish-Lithuanian), which are filled with thick Reefian, Paleozoic, Mesozoic and Cenozoic sediments.

The Baltic synclise is separated from the Moscow synclise by the Latvian saddle and is a residual depression that first arose in the Late Paleozoic in place of the western part of the ancient Baltic trough, which in Reefian and Lower Paleozoic times extended across the Russian craton, dividing its ancient shields (separating the Baltic shield from the Sarmatian and Volga-Urals shields). The USSR contains only the east central part of this synclise; the center lies under the southern part of the Baltic Sea.

The Polish-Lithuanian synclise dates from Mesozoic, mainly Upper Cretaceous, times. The thickness of these sediments, which are best developed stratigraphically, reaches 700 meters. The eastern limb of the synclise is complicated by Pre-Cretaceous transverse faulting. The largest of these faults are the east-west Vladimir-Volynskiy fault (with a throw of at least 1,500 meters) and the marginal east-west faults of the Brest trough.

The history of development of the Russian craton clearly falls into several stages. The first covers Reefian and Lower Cambrian times, and the second Ordovician and Silurian times. In Reefian times the general strike of the major structural elements was east and northeast. The Baltic shield arose in the northern part of the craton; to the south the Baltic trough went through its long history of development; farther south were the large Sarmatian and Volga-Urals shields separated by the deep Pachelma trough; in the extreme southeast, the Caspian synclise was apparently already in existence. During the same period, i.e. the Reefian and the start of the Cambrian, the Reefian geosynclinal system of the Varanger Peninsula and the Timan was completed and the Russian craton grew somewhat in size.

Major changes took place in the structure of the northwestern part of the Russian craton during the Ordovician and Silurian in connection with Caledonian folding in the Grampians geosynclinal system.

Characteristic of the Lower Devonian is a predominance of uplifting movements that ended the accumulation of sediments over a large part of the craton. During this time sediments accumulated only in downwarped sections of the southwestern margin of the craton, in the western part of the Baltic trough, and possibly in the Caspian synclise.

The Middle and Upper Devonian saw further changes in the structure of the craton. The Donets trough was formed, dividing the Sarmatian shield into the Ukrainian shield and the Byelorussian and Voronezh anticlises. The formation of the Moscow synclise was intensified and the entire eastern part of the craton began to subside intensively (forming A. D. Arkhangelskiy's East Russian Depression). This stage of development continued until the Lower Triassic, whose sediments are closely associated with Upper Permian rocks both in cross section and in distribution over the craton. The third stage thus resulted in an almost easterly strike of structures in the western part of the craton, and in the formation of a large north-south trough in the eastern part. The Middle and Upper Devonian epoch, which was a major turning point in the

structural development of the craton, was accompanied by greater tectonic activity. This gave rise to volcanic activity in a number of areas, leading to the formations of thick volcanic strata (in the Donets trough and in the Timan).

The fourth stage of development, starting at the beginning of the Jurassic, was marked by intensive development of all depressions in the southern part of the craton (the Caspian and Ukrainian synclise and the Lvov trough), complicated by local faulting; and by intensified growth of the Timan and further downwarping of the Baltic, Moscow and Pechora synclises. During this period the easterly strike of troughs and uplifts was again dominant.

Siberian Craton

Central Siberia and large parts of Eastern Siberia are located within the Precambrian Siberian craton. The western boundary of the craton is shown on the map on the basis of geophysical surveys going roughly along the Yenisei River from Krasnoyarsk in the south to Dudinka in the north. In the Dudinka area the edge of the craton turns sharply eastward, extending to the mouth of the Khatanga River and proceeds further in a slight bend to the mouth of the Lena River. At this point the boundary of the craton turns south at a right angle and, forming a sharp re-entrant arc, proceeds along the valley of the Lena River to the mouth of the Aldan, then along the Aldan, and making another right-angle bend, to the Sea of Okhotsk. Here the boundary makes another deep protrusion, turns sharply southwest and then west, and, following the foot of the northern slopes of the Stanovoi Range, extends to the southern end of Lake Baikal. From here, changing once again direction, the boundary goes northwest between the Precambrian and Caledonian parts of the Eastern Sayan as far as the Yenisei River near Krasnoyarsk. Like the Russian craton, the Siberian is thus characterized by an angularity of outline and pronounced rectilinearity of boundaries.

The basement of the Siberian craton was formed during the period of Archean, Proterozoic and Baikalian folding. Baikalian folding is believed to have produced the basement of the western part of the craton in the Yenisei ridge and in the southern part, in the Baikal uplands. The folded basement of the Vilyui synclise is probably also of Baikalian age. The rest of the basement dates from the Archean and Proterozoic. Among Archean formations in some places (such as the Aldan shield) are sections of ancient cratons formed in early Proterozoic times.

Archean folds in the Siberian craton form a system of complex arcs. These arcs strike northwest in the Aldan upland and change to northeast in the Baikal upland. At the southern end of Lake Baikal, the strike of these Archean folds changes once again to northwest. Within the Anabar block Archean folds also strike northwest.

The Proterozoic folds follow the strike of the Archean folds as a rule. In the Lower Proterozoic we find zones of geanticlinal uplifts and geosynclinal troughs that can be completely correlated in terms of character of formations, folding and magmatism with similar structural zones of Paleozoic geosynclinal areas (the basin of the Vitim River and the Eastern Sayan).

Baikalian folds form a system of relative narrow geosynclinal troughs separated from one another by equally narrow geanticlinal uplifts. Sedimentary and volcanic strata have been plicated into a system of complex linear folds that are clearly inherited from the preceding Proterozoic stage.

Magmatic activity is much in evidence among the Precambrian formations of the basement of the Siberian craton. In the Archean, ultrametamorphic rather than igneous rocks predominate, and the earlies ultrabasics are found. Two stages of granitization have been identified in the Archean. In the Proterozoic, there was evidently widespread volcanic activity which led to the presence of a thick spilite-keratophyre formation. More or less contemporary with that formation were great basic intrusions (anorthosites, labradorites followed somewhat later by granitoid intrusions.

Magmatic activity was also typical of the Reefian stage. It is evidenced by the accumulation of thick prophyry beds in the Baikal upland, the presence of large gabbro

diorite intrusions, and, toward the end of the stage, of intrusions of normal granites. The very final phases of Baikalian folding were accompanied by ultrabasic magmatism. Of particular interest are ultrabasic veins cutting through Reefian cratonic formations in the southwestern part of the craton (Chadobets uplift).

The surface of the folded basement of the Siberian craton shows relatively little relief. It outcrops in the crest of the Anabar block in the northern part of the craton; in the Archean and Proterozoic formations of the Aldan shield in the southeast; in the Reefian formations of the Baikal folded zone; and in the northern zone of the Eastern Sayan, which is the turned-up southern edge of the Siberian craton. On the western margin of the craton, the folded basement outcrops in the crests of large uplifts striking north along the Yenisei River (the Yeniseisk uplift and the Turukhansk uplift). Aside from the above-mentioned positive structures, the basement is submerged to varying depths, forming a series of large depressions that are filled with thick sediments. The average depth of the basement can be determined for the present only by calculating the thicknesses of the cross section of the cratonic mantle. On the slopes of large uplifts (such as the Aldan and Anabar uplifts), the cratonic mantle is relatively thin (500 to 2,000 meters). However, the depth becomes much greater in the central parts of large synclises — 7 to 8 kilometers in the Vilyuy synclise and 5 to 6 kilometers in the Tunguska synclise.

The Anabar block is a group of nonhomogeneous uplifts. Its core is made up of deeply metamorphosed Archean rocks overlain unconformably by Reefian, Cambrian and Ordovician cratonic formations. The northern limb of the block is complicated by the small but abrupt Popigai uplift, surrounded by a system of faults. In its northeastern corner the block contains the Olenek uplift, and in the southeast the Muna uplift, the crests of which contain outcrops of the lower horizons of the cratonic mantle. Between the Muna uplift and the central part of the Anabar block is the relatively shallow Olenek trough, which contains all three divisions of the Cambrian system with a thickness of more than 1,500 meters.

Facies analysis of Lower Paleozoic sediments of the Anabar block shows that they once covered the block in its entirety and that Archean outcrops in its present crest resulted from later uplift and erosion. That is why the Anabar Precambrian structure must be called a block rather than a shield.

The Aldan shield, made up of Archean rocks over a large part of its area, dips gently to the Vilyui synclise in the north and more sharply to the Berezovka trough in the northwest.

The Baikal folded zone, which adjoins the Aldan shield in the west, constitutes a system of folds that strike northeast, then change their strike to east in the upper reaches of the Bolshoi Patom and Zhuya rivers, and finally to east-southeast. The Baikal folded system is bounded on the northwest and north by the distinctive systems of the Angara-Lena and Berezovka troughs. Both of these are ancient marginal troughs dating from Baikalian folding. They are filled with a Reefian flysch-like formation on which rest Lower Cambrian clastic salt-bearing rocks and limestones. The rocks that form these troughs have been plicated into a system of narrow anticlines and broad synclines that gradually smooth out in the direction of the interior of the craton. In terms of their structural position, their stratigraphyic sequence and their conditions of tectonic development, the Angara-Lena and Berezovka troughs appear to be completely analogous to the marginal troughs of later geologic epochs. The only major difference is the extraordinary width of the Angara-Lena trough, which reaches 300 kilometers.

The Reefian folded structures of the Baikal region are continued in the east by the Yablonovyy-Stanovoi anticlinorium. This structure borders the Aldan shield of the Siberian craton on the south, is distinguished by the great depth of its erosional cross-section and is made up predominantly by Archean and Proterozoic metamorphosed rocks, intruded by ancient granites of various ages. The boundary zone between the Aldan shield and the Yablonovyy-Stanovoi anticlinorium was apparently a system of deep fractures along which anorthosite and gabbro-anorthosite intrusions found their way in

the Dzhugdzhur Range, the valley of the Olekma River and elsewhere. The same zone was used in later stages of development of Reefian folding by large intrusive granitoid masses, which led to the formation of a complex series of injection gneisses and migmatices.

The Yeniseisk and Turukhansk uplifts, which border the Siberian craton on the west, differ sharply from the Baikal zone because of the absence of a marginal trough. In terms of morphology and position, the Turukhansk uplift rather seems like a cratonic structure. The Khantayka-Rybnoye uplift, situated farther noth, is a gentle anticlinal ridge, in whose crest the Tunguska series unconformably cuts through sediments ranging from the Lower Carboniferous to the Ordovician.

In the western part of the Siberian craton, between the north-south Yenisei uplifts, the northwestern part of the Eastern Sayan, the Angara-Lena marginal trough and the Anabar block, is the Tunguska synclise. It is a deep but generally flat depression in the surface of the folded basement of the craton, containing rather thick sediments. Formations ranging from the Reefian to the Silurian are made up of shales, sandstones and limestones. The Reefian sediments have a thickness of 3 to 4 kilometers, the Cambrian 2 to 3 kilometers and the Ordovician and Silurian 0.5 kilometer. Devonian formations, which do not occur everywhere (mainly in the northwest), consist of red-colored shale and marl, and in part marine limestones of the Middle Devonion, with an over-all thickness of 300 to 600 meters. The thickness of the Carboniferous and Permian coal-bearing series ranges from 100 to 800 meters. The Triassic is of great importance in the cross section of the Tunguska synclise. Its lower horizons (a tuffaceous series) are 500 to 700 meters thick in the north, and the upper horizons (a tuff and lava series) 1,500 meters. The rocks of the Tunguska series are invaded by sills and intersecting bodies of basic rock, the so-called trap rock, which occurs mainly along the margins of the synclise, where it is apparently associated with a system of deep fractures. The trap rock dates from the Triassic. The most recent magmatic formations are ultrabasic dikes and associated kimberlite pipes, which were apparently formed in the Jurassic. In part they may be even younger.

In general the Tunguska synclise is made up of virtually flat strata. However, in a number of places, especially in the southwestern half, individual domes similar to the placanticlines of the Russian craton rise from the vast, flat trough.

The Vilyui synclise has quite a different structure. It is a young Mesozoic depression that was formed on a folded basement much younger than that of the Tunguska depression, and was closely associated in its development with the re-entrant arc of the Verkhoyansk marginal trough. There is some reason to believe that the Vilyui synclise is actually a huge transverse trough in the body of the Siberian craton that was complicated by faulting and was closely associated in its development with the Verkhoyansk folded zone.

The Vilyui synclise is filled with Cambrian, Ordovician and Silurian sediments more than 3 kilometers thick, including land-derived, salt-bearing and limestone rocks. Its central section undoubtedly contains red-colored, partly tuffaceous rocks of the Devonian and Carboniferous up to 500 meters in thickness. Thus far no Permian and Triassic rocks have been identified, although they are more than likely to exist in the central and especially the eastern parts of the synclise. The Jurassic and Cretaceous systems are represented by land-derived rocks mainly of continental, but in part also of marine origin, which are coal-bearing in spots and in many ways recall the molasse formation. The thickness of these sediments reaches 4 kilometers in the center of the syncline. In contrast to the Tunguska synclise, the Vilyui structure has virtually no evidence of volcanism.

The sediments that fill the Vilyui synclise are only slightly disturbed in general. Its axial section contains the Kempendyai salt domes, whose cores consist of Cambrian salt. Several gentle brachianticlinal folds are known in the lower reaches of the Vilyui River.

A special place in the structure of the southern margins of the Siberian craton

must be given to a series of Mesozoic epressions filled with Jurassic land-erived coal-bearing sediments, a series f deeper and younger depressions filled vith Tertiary and Quaternary formations. The first series of relatively shallow but arge depressions extends along the north-rn foot of the Eastern Sayan (Rybinskoye, Kansk, Irkutsk) and farther east within the Aldan shield (Chulman). The second eries includes the Lake Baikal, Barguzin, Verkhneangarsk and Chara depressions. These are larger structures, usually com-plicated by faulting along one of their limbs, and sometimes constitute actual rabens. Their origin is related to in-ensive young vertical movements that esulted in deep-seated arch folding and vere accompanied by intensive volcanic ctivity (basalts of the Vitim River basin, he southern shores of Lake Baikal and ther areas).

Regions of Paleozoic Folding

Paleozoic folded structures are videspread in the territory of the USSR. They border on the Russian craton in the outhwest and south, make up the moun-ains of Central Asia and Kazakhstan, the Urals, the basement of the West Siberian nd Turan lowlands, the Taimyr and the nountains of southern Siberia. Over huge reas of the Turan and Western Siberia hese structures are covered by varying hicknesses of Mesozoic and Cenozoic nantle rock. The Paleozoic rocks outcrop n mountain ranges and uplands.

The Paleozoic folded formations can e divided into zones of Caledonian and Hercynian folding, although this division is ess clear in the USSR than in Western Europe.

Caledonian Folded Formations

Caledonian Folded Formations are learly distinguished in Norway and in the rc-shaped mountain belt that encloses the iberian craton on the south. The Cale-onian formations of Scandinavia, which nclose the Baltic shield of the Russian raton in the northwest and north, have een displaced toward the southeast in a ystem of low-angle overthrusts. These verthrusts have brought together the ower Paleozoic cratonic formations of the northwest slope of the platform and the allochthonous geosynclinal formations of the same age.

Areas of ancient consolidation that are of nearly the same age as the Cale-donian formations can be distinguished in the Paleozoic folded structures of the northern Tien Shan and in the western part of Central Kazakhstan, as well as in the northern zone of the Taimyr and on the islands of Severnaya Zemlya. How-ever, their structure, history of develop-ment and relationships with adjoining Hercynian formations are so distinctive that they must be considered together with the latter.

A number of distinctive aspects also characterize the Caledonian formations in southern Siberia. On the tectonic map these structures include: the southwestern part of the Eastern Sayan, the Khamar-Daban, the Lake Kosogol area, the Sangilen and adjoining areas of northern Mongolia, the block-fold structures of Tuva, the Western Sayan, the Kuznetsk Alatau, Gornaya Shoriya and the Salair, as well as the intervening intermontane depressions (Chulym-Yenisei, Syda-Yerba, Minusinsk and Usa) and troughs (Tuva and Uymen-Lebed).

The Caledonian formations are separated from the Siberian craton by the East Sayan outcrop of the cratonic base-ment, which forms a marginal uplift in the structure of the craton. This outcrop, which is often called the chief anticlinorium of the Eastern Sayan or the Protero-Sayan, adjoins the Caledonian structure of the southwestern slope of the Eastern Sayan along a deep-seated fracture, striking NW-SE from Krasnoyarsk to the south-western end of Lake Baikal.

Deep-seated faults, along which major structural elements always adjoin in folded regions, can be traced especially well in the Caledonian region of southern Siberia because of its great degree of uplift and deep erosional cross section. Such a fault forms the boundary between the Western Sayan and Tuva. Another follows the north-ern face of the Western Sayan, separating it from the Minusinsk depression and the structures of Gornaya Shoriya. We can also easily trace a fault that proceeds

along the western margin of the Kuznetsk Alatau and the Gornaya Shoriya. In the southwest a large fault separates the structures striking northeast in the Tuva trough and the structures striking northwest in the Eastern Tannu-Ola and the East Tuva uplands. Another fault separates the Eastern Tannu-Ola from the Sangilen.

The long period of development of these deep-seated fractures of the Siberian Caledonian formations is shown in many cases by the sharp differences in the stratigraphic cross sections on both sides of the fault, the differences being expressed in terms both of thicknesses and of facies. In addition, the early stages of faulting in the Lower Cambrian were associated with ultrabasic intrusions, and these fault zones in general display the most marked evidence of magmatic activity.

Another characteristic aspect of the structure of the Caledonian formations in southern Siberia is the differences in length of development of the various zones and sections.

The oldest are the Caledonian formations of the Eastern Sayan, of eastern and southeastern Tuva, the Kuznetsk Alatau and Gornaya Shoriya. Their geosynclinal development covers the entire Proterozoic (including the Reefian) and ends in the start of the Upper Cambrian.

The Caledonian formations of the Eastern Sayan contain Lower Proterozoic metamorphosed rocks (graphitic marbles, bedded marbles, crystalline schists) and slightly metamorphosed rocks of the so-called Kuvai series (dark and light-colored quartzites, quartz-mica schists, marble horizons and so forth), classified as Reefian. In some places the Kuvai series rests conformably on the Lower Proterozoic, elsewhere unconformably. The Reefian sediments, in turn, are separated from the overlying Cambrian rocks by a break and an angular unconformity. This unconformity appears especially clearly in the northwestern part of the Eastern Sayan, in the lower and middle course of the Mana River, as well as farther southeast near the source of the Kazir River, along the left tributaries of the Oka River (in the Tissa-Sarkhoi watershed), and in the basin of the Khoral River in Tuva. The Cambrian sediments consist of an extrusive schistose greenstone formation enclosing lenses and entire beds of reef limestones with Archaeocyathinae. The Eastern Sayan thus displays clear evidence both of Baikalian folding of the end of the Precambrian, and of Cambrian folding.

In terms of age, the acidic intrusive bodies of the Eastern Sayan fall into three groups: Precambrian, Lower Paleozoic (apparently mainly pre-Ordovician) and Middle Paleozoic. Rocks of the last named group intrude the extrusive series of the Lower Devonian and also form part of Middle Devonian red-colored conglomerate pebbles.

The Kuznetsk Alatau apparently displays a closer relationship between Reefian and Cambrian sediments. Here the main period of folding probably occurred in the Cambrian. Cambrian sediments are unusually well developed in the Kuznetsk Alatau, Gornaya Shoriya, the southern part of Tuva (in the Eastern Tannu-Ola) and in part in the eastern section of Tuva, being represented mainly by greenstone extrusives, tuffs, tuff conglomerates, limestones, siliceous rocks and shales, relating predominantly to the lower division of the Cambrian system. Here also, acidic intrusions date chiefly from pre-Silurian, and probably even pre-Ordovician, times, i.e. they are of early Caledonian origin.

In the Western Sayan and the Salair geosynclinal conditions appear to have continued longer than in the preceding regions. The cross section of geosynclinal formations of these areas covers the entire range from the Precambrian to at least the Middle Ordovician.

In the Western Sayan, the cores of the large anticlinoria are made up of heavily metamorphosed Precambrian rocks, consisting chiefly of various crystalline schists injected with quartz along bedding and cleavage planes. These schists also include jaspilites. The Lower Cambrian of the southern and northern slopes of the Western Sayan consists of an extrusive-schistose spilite-keratophyre formation with trilobitic and archaeocyathic limestone beds. Occasional Middle Cambrian sediments consist of limestones, shales and extrusives.

These formations are overlain by the Alasug series, which in some areas is also known as the Kurtushiba or Azhik series. It consists of flysch-like greenish-grey clayey-marly shales and shaly siltstones, often underlain by conglomerates. This series is very thick as a rule, attaining 2 to 5 kilometers. Its upper members display a sparse Lower Ordovician fauna. Its lower members may belong to the Upper Cambrian. The geosynclinal cross section of the Western Sayan is topped by green and red sandstones with interbedded argillites, shales and limestone lenses that are rich in Middle Ordovician fauna. These rocks attain a thickness of up to 2 kilometers. All these sediments are intruded by granitoids. The cross section of the Salair is of a similar character.

Structurally the Western Sayan represents a complex folded system that is divided on the tectonic map into: the Western Sayan (or Dzhebash) and Kurtushiba anticlinoria and the intervening Usa synclinorium.

The last stage of development of the Caledonian formations in southern Siberia is marked by the formation on folded basements of various ages of large superimposed intermontane depressions and inherited troughs. The first type includes the Chulym-Yenisei, Syda-Yerba, Minusinsk and Usa depressions. Typical inherited troughs are those of Tuva and Uymen-Lebed.

The superimposed depressions have a simpler internal structure than the inherited troughs. Their cross sections are less complete and sometimes also thinner. They often have almost isometric outlines. The age of the folded basement is usually uniform under the entire depression.

The Tuva trough, on the other hand, has the following characteristics: folded basement of various ages; asymmetric structure, which is evident both in the over-all structure of the trough and in the areal distribution of formations; greater thickness and completeness of the stratigraphic cross section; much more complicated internal tectonics, and a generally elongated form.

Both in the superimposed depressions and in the inherited troughs, the sedimentary fill is separated from the basement rocks by a break and large angular unconformity, though this break is somewhat smaller in the inherited troughs.

The northern group of depressions (Chulym-Yenisei, Syda-Yerba, Minusinsk) originated at the start of the Devonian in connection with the occurrence of faults of varying lengths and strikes that broke up the early Paleozoic folded basement into separate blocks. The formation of these depressions started with the accumulation of thick beds of predominantly red-colored extrusive rocks. In some places these extrusives alternate with coarse red-colored clastic rocks. Starting with the Middle Devonian, the depressions were filled with red-colored molasse, mainly of continental but occasionally also of marine origin, overlain in turn by gray-colored, land-derived Lower Carboniferous beds and coal-bearing Lower Permian sediments. The red-colored Devonian molasse corresponds entirely to the Old Red of the Caledonian formations in Western Europe.

The Tuva trough originated in the Silurian and continued to develop through the Middle and Upper Paleozoic until the end of the Carboniferous. In addition to the above-mentioned formations that accumulated in the Minusinsk depressions, the Tuva trough also contains at the bottom shallow epicontinental marine formations of the Silurian, consisting of argillaceous limestone sediments, and in part flysch-like rocks. The Devonian molasse contains in some places salt-bearing sediments, while the coal-bearing rocks appear earlier than in the Minusinsk depressions, as early as the Middle and Upper Carboniferous.

The characteristic red-colored extrusive and land-derived formation is not of the same age in the various depressions and troughs. Its earliest appearance (toward the end of the Silurian) was in the Tuva trough, followed in the Lower Devonian in the Usa, Minusinsk and adjacent depressions, and finally (in the Middle Devonian) in the Uymen-Lebed trough.

The dislocations of all the intermontane depressions and troughs consist of

block faulting and folding. In the depressions, these dislocations are most evident along the periphery, next to the large enclosing uplifts. In the inner sections of the depressions, the dislocations are less pronounced, taking the form of faults, flexures, domes, gentle troughs and box-like anticlines. More or less large uplifts divide the depressions into a series of smaller structures. The Chulym-Yenisei depression, for example, is divided by the anticlinal Solgon uplift and the Kopyevo dome into the Chebakovo-Balakhta depression in the south and the Nazarovo depression in the north.

The inherited Tuva trough has a complex internal structure. The uplifted Bayangol zone in its center divides the trough into three parts: the Ulug-Khem section in the center, the Khemchik-Ubsanur section in the southwest, and the Biy-Khem section in the southeast. The central section is characterized by a large number of breaks and angular unconformities, and by the thinness of stratigraphic horizons; all its structures are angular blocks or short-limbed folds. In the southwest section, on the other hand, the thickness of the sedimentary fill is much greater, breaks are less evident or entirely absent, and dislocations are usually linear in nature.

The red-colored extrusive formation of the northern depressions is intruded by nephelite rocks, but the upper sediments are intruded only by basic dikes. Small granitic bodies are found in the Tuva trough, but intrusions of diabasic porphyries, gabbro-diabases, diorites and quartz diorites in the Middle Devonian are more common.

Hercynian Folded Formations.

We will start our survey of Hercynian folded formations with the Altai, Central Kazakhstan and the Tien Shan.

Altai, Central Kazakhstan and Tien Shan. Paleozoic folded structures situated between the Precambrian Tarim block in the south and the Caledonian formations on the southern margins of the Siberian craton in the north fall clearly into three major zones, differing in the age of folding.

The middle zone, which covers the western part of Central Kazakhstan and the northern arcs of the Tien Shan, completed its geosynclinal development in the Silurian and can therefore be assigned to Caledonian folding. However, the symmetrically located southern arcs of the Tien Shan, and the eastern parts of Central Kazakhstan, the Dzungarian Alatau and the Altai are folded structures of Hercynian age.

The ancient folds of the northern Tien Shan and the western part of Central Kazakhstan consist of deeply metamorphosed Archean and Proterozoic rocks that form the cores of large anticlinoria (Kokchetau, Ulutau, Betpakdala, Karatau). The limbs of these uplifts consist of Reefian and Cambrian rocks. Thick sediments of usually land-derived Ordovician rocks have accumulated in the troughs. The upper horizons of the northernmost trough (the Kalmyk-Kul and Stepnyak synclinorium) are flysch-like in character. The Silurian and, in the northern Tien Shan, the Devonian are as a general rule lacking in the middle zone. In Central Kazakhstan, the Lower and Middle Devonian consists of volcanic rocks laid down with sharp unconformity on top of eroded Caledonian formations. The ancient folded rocks are invaded by ultra- basic intrusions, granodiorites and granites of pre-Lower Devonian age. The devonian volcanic rocks are invaded by large granite intrusions of Middle Devonian age.

The upper structural stage of the middle zone consists of Upper Devonian, Carboniferous and Permian sediments, which constitute a very characteristic series of sedimentary and, in the case of the northern Tien Shan, extrusive formations. In Central Kazakhstan the bottom of this series consists of molasse of the Frasnian stage, followed upward by marine limestones of the Famennian stage and the Lower Carboniferous, which are overlain in turn by molasse of the Upper Paleozoic, often with a sharp unconformity. This upper stage fills large interior depressions, such as the Teniz, Dzhezkazgan and Chu depressions. Block-fault dislocations (flexures, domes, irregular troughs) are widespread both within these depressions and along their edges. In many respects the structure of these depressions recalls that of the interior depressions of the Caledonian zone of southern Siberia,

uch as the Chulym-Yenisei depression.

The region of the Dzungarian Alatau, he eastern part of Central Kazakhstan and he Altay consist of a series of anticlinoria nd synclinoria that widen and diverge oward the northwest and approach each ther toward the southeast. The anticlinoria f this region, which include the Dzun- arian, Chingiz, Akbastau, Tekturmas, 'erekti and Talitsa uplifts, contain cores f Lower Paleozoic, Reefian and Middle 'roterozoic rocks that have been plicated nto a system of complex folds, often fan- ike in form. The limbs of the anticlinoria onsist of Silurian and Devonian rocks that orm somewhat simpler folds.

The large synclinoria between the anti- linoria are filled with volcanic and sedi- hentary rocks of the upper horizons of the evonian, the Carboniferous and the Per- nian. These rocks attain great thicknesses f up to 10 kilometers. Of special note are he system of Semipalatinsk troughs and he North Balkhash synclinorium, whose ross section is the thickest and most omplete. The volcanic geosynclinal for- hations that fill these depressions range hrough the entire Paleozoic system up to he Permian, and possibly even to the ower Triassic inclusive. These syn- linoria are sections of the geosynclinal egion that have retained geosynclinal onditions for the longest time. In the orthwest, the Karaganda synclinorium nd adjacent depressions are filled in the pper Paleozoic with a very tnick coal- earing formation (attaining 6 kilometers), hich rests on formations similar to the Vestern European culm.

Magmatic activity is much in evidence n the Hercynian zone of Kazakhstan and he Altai, both in its extrusive and in its ntrusive forms. Among the latter are ones of ancient (possibly Reefian) ultra- asic intrusions, granitoids of Devonian nd Middle Carboniferous age, and more ecent granite bodies that have invaded olcanic and sedimentary rocks of the Car- oniferous.

A major role in the structure of the lta, Central Kazakhstan and the Tien Shan s played by zones of deep-seated fractures hat have developed over a long period of me. They include the Karatau, Dzhalair- Nayman, Uspenskiy and Irtysh zones. They provide the principal controls for the distribution of magmatic and mineral ore formations.

A characteristic aspect of the tectonic structure of Central Kazakhstan is the unstable character of the strike of structures. Various areas contain structures that strike north, northeast or northwest. This aspect distinguishes Central Kazakhstan from the Urals, where structures strike uniformly north-south.

The Caledonian formations of the western part of Central Kazakhstan and the northern Tien Shan constitute a zone of early consolidation within the Urals-Siberian Paleozoic geosynclinal region. These structures constitute one of the centers where geosynclinal conditions began to die out, with the quiescence later spreading to adjoining areas. The boundary between the Hercynian formations of the Altai and the Caledonian formations of southern Siberia lies in the Anuy-Chuya synclinorium. However, this synclinorium does not have the structural characteristics of a marginal trough such as we might expect on a Caledonian folded basement along the margin of Hercynian formations.

The probably continuation of the folded system of the Altai is the Tom-Kolyvan folded zone, which cuts off the Caledonian folds of the Salair in the north. The overall character of the cross section of this zone points to the presence there toward the end of the Middle Paleozoic of a rather deep and complex trough that was subjected later to Hercynian folding. At right angle to the Tom-Kolyvan zone is the large, deep Kuznetsk trough, in the form of a wedge penetrating between the Salair and the Kuznetsk Alatau. This depression, which is structurally quite distinctive, has the character of a transverse marginal trough of Hercynian folding that developed on a Caledonian folded basement. The long period of formation and the huge thicknesses of coal-bearing sediments, whose upper horizons belong to the Permian, as well as the almost total absence of evidences of magmatic activity clearly distinguish the Kuznetsk trough from the Minusinsk and other depressions situated farther east and leave no doubt about its Hercynian age.

The Hercynian structures of the southern Tien Shan differ sharply from the Caledonian middle zone in having a system of deep-seated fractures that form a huge arc slightly convex toward the south. Along this arc we find a sharp change in the types of cross sections of Middle and Upper Paleozoic formations. This region contains widespread thick extrusive, shale and limestone formations of the Silurian, Devonian and Carboniferous, that make up the Alai, Turkestan, Zeravshan, Kokshaal and other ranges of the southern Tien Shan. In large depressions, such as those of Surmetash and Karachatir, the coarse molasse of the Upper Paleozoic attain huge thicknesses. Large blocks of Hercynian (Middle Carboniferous) granites have been found in the Gissar, the Alai and the Tashkent area.

The Hercynian rocks have been plicated into a system of east-west folds as a result of movements in Carboniferous times and later. While simple forms predominate among dislocations in the troughs, there are also zones of rather intensive folding In the large anticlinal uplifts, late Hercynian movements took the form of faulting and alkaline and subalkaline intrusions.

Urals and Novaya Zemlya. The Urals are in example of one of the largest linear folded systems with a consistent strike of its principal structural elements. Characteristic of the Urals are the great stability in the character of cross sections along the strike of the system and their great variability at right angle to the strike. Many stratigraphic sequences found in the southern Urals are identical in lithology with sequences of the same age in corresponding tectonic zones of the Polar Urals.

In an east-west section of the Urals we can distinguish at least three series of geosynclinal troughs separated by geanticlinal uplifts. These troughs and uplifts differ substantially from each other in terms of cross sections, magmatism and degree of metamorphism, so that in the geological literature of the Urals they are often described as distinctive tectonic "zones" having specific designations.

In a more general analysis of the structure of the Urals, these folded structures can be divided into two zones: an eastern and a western.

The western zone of the Urals consists of a system of large uplifts and troughs of varying structure. In the large uplifts (the Bashkir anticlinorium and the Kolva-Vishera anticlinorium), there are outcrops of slightly metamorphosed Reefian sediments, whose thickness exceeds 10 kilometers. Conglomerates, sandstones and limestones are well represented. The fragmental material that produced the Reefian land-derived rocks originated on adjoining parts of the Russian craton, probably mainly within the area of the present Volga-Urals anticlise. As we proceed eastward to the Uraltau anticlinorium, the structure of these sediments begins to change. Shales and volcanic rocks become dominant, and the degree of metamorphism increases sharply. The intensity of folding also increases from west to east. While broad, open folds are typical of the areas adjoining the Russian craton, the Uraltau anticlinorium contains closed, often isoclinal, folds that are overturned either toward the west, as in the middle and northern Urals, or toward the east, as in the southern and Polar Urals. The shape of the folds as viewed from the top also changes from west to east. Near the craton the folds are arc-shaped, especially in the so-called Ufa amphitheatre. Farther east they straighten out and strike due north and south.

The anticlinoria of the western zone are separated by large synclinoria, including those of Zilair and Lemva. These depressions are filled with a typical geosynclinal series of Paleozoic sediments: shales, graywackes with intercalated volcanic rocks, and in the upper horizons (Carboniferous to Lower Permian) with a flysch formation. Toward the west, near the craton, these sediments are abruptly replaced by thinner Devonian and Carboniferous limestones that are quite similar in cross section to sediments of the Russian craton dating from the same period. This sharp facies boundary is apparently related to a system of deep-seated fractures that has developed over a long period of time and is the marginal seam separating the Urals from the Russian craton.

Intrusions are quite limited in the western zone. They include ultrabasic bodies in the Zilair synclinorium (Bolshoi and Malyy Krak, small bodies in the

naytantau Mountains), small intersecting itrusions of gabbro-diabases, occasional mall bodies of acidic and alkaline rocks the Berdyaush body of Rapakivi-type ranites and younger nephelite-syenite itrusions in the Middle Urals; also granic bodies in the Northern and Polar Urals).

The Pay-Khoy and Novaya Zemlya have i general the same type of structure as he western zone of the Urals. Sedimentary ocks predominate in these northern tructures, and the folds are generally verturned to the west.

The eastern zone of the Urals as a whole has subsided in relation to the western zone. Precambrian and Lower Paleooic sediments are therefore deeply subierged and even in uplifts make up relavely limited areas. A principal characeristic of this zone is the extraordinarily itensive development of various types of iagmatic activity.

The western part of the eastern zone f the Urals contains an almost continuous elt of large, narrow synclinoria, including hose of Magnitogorsk, Tagil, and Shchuche in the Polar Urals, filled with Silurian, evonian and sometimes Lower Carbonferous volcanics, which are occasionally ssociated with large reef limestone bodies.

Graywackes are of importance in the pper horizons, starting with the Upper evonian, and flysch-like sediments are ometimes found in the Lower Carbonferous. Along the Ural-Tau, we thus find sharp change in the Paleozoic cross ection between the western and eastern ones. This is apparently related to the resence of a system of deep-seated ractures that have developed over a long eriod of time along the boundary of the estern and eastern zones. This fracture ystem is marked on the surface by a elt of ultrabasics, gabbro, quartz diorites nd plagioclase granites. These intrusions re of the same magmatic origin as the olcanic rocks of the synclinoria and it may e supposed that the above-mentioned ssures provided one of the feeded conuits for the extrusives. A second zone of eep-seated fractures, less clearly marked, ay mark the eastern side of the aboveentioned synclinoria. The transverse plift that separates the Magnitogorsk and Tagil synclinoria contains the famous nephlite-syenite bodies of the Ilmen Mountains.

East of the Tagil synclinorium of the Southern Urals is the large uplift of the Urals-Tobol anti-clinorium. There, Silurian and younger sediments are the same type as in the synclinoria, though thinner and divided into a number of sequences separated by unconformities. These sediments rest of metamorphosed shales and volcanics of the Lower Siurian, Ordovician, Cambrian and Precambrian that have been converted into schists and gneisses in some places. The Urals-Tobol anticlinorium contains widespread Hercynian and younger granitoid bodies, as well as smaller ultrabasic intrusions.

East of the Urals-Tobol anticlinorium, in the basin of the Tobol River, a section of the Ayat synclinorium outcrops from under a mantle of Mesozoic and Tertiary cratonic sediments. This synclinorium resembles in several respects those of Tagil and Magnitogorsk, but differs from them in the wider occurrence of granite bodies and the presence of extensive fields of ancient metamorphosed rocks. Moreover the development of this trough proceeded more rapidly, since graywacke appeared as early as the start of the Middle Devonian.

Large areas of the Ayat synclinorium and the northern part of the Urals-Tobol anticlinorium are covered with a continuous cratonic mantle of Mesozoic and Tertiary sediments beneath which the ancient rocks can be reached only by deep borings (see below).

Some areas of the Urals deviate from the dominant north-south strike. The best known of these deviations is the Ufa amphitheatre, which was formed against an uplifted protruding section of the Russian craton (the Volga-Urals anticlise). Here the western zone of the Urals is sharply compressed and its structures form an arc-like bend, whose extremities strike east-west. In the eastern zone, the strike is consistently north-south, except for the transverse saddle between the Tagil and Magnitogorsk synclinoria.

A second bend, possibly similar to the

Ufa structure but less clearly marked, is formed by structures of the western zone of the Urals in the extreme south, at the latitude of Aktyubinsk, against the Khobda protrusion of the basement of the Russian craton within the present Caspian synclise. This protrusion is buried under Mesozoic and Cenozoic formations but apparently exists in the Paleozoic.

In the northern part of the Urals, the strike changes from north to northeast and even almost east. Still farther north, the strike returns to north and swings northwest, as in the Pai-Khoi. These strike changes are caused by factors other than the ones that produced the Ufa and Aktyubinsk amphitheatres. In this case we are dealing with a system of large, complex fractures that is expressed more clearly in the eastern than in the western zone of the Urals. In Novaya Zemlya the strike changes from northwest to north-northwest under similar conditions, but the structure of this section is much simpler.

There are many hypotheses concerning the southern subterranean and the northern submarine continuations of the Urals. It is now assumed that the Upper Paleozoic folded system of the Urals died out in the south and became submerged in the area of the present Mugodzhar hills without joining up with the Donets Basin or the Tien Shan. The Urals are apparently separated from the Tien Shan by a continuous east-west belt of Upper Paleozoic molasse that extends eastward through the northern Ustyurt and the Aral Sea to the northern Kyzyl-Kum. The submergence of several large structural elements in the north, in the area of the Polar Urals and the Pay-Khoy, can also be regarded as a sign that the entire folded system dies out in that direction as well.

The folded structures of the Urals are separated from the Russian craton by a system of deep depressions of the Urals marginal trough. These depressions originated in the final stages of geosynclinal development in the Urals (Upper Carboniferous to the Lower Permian). They were closed off at the time of completion of mountain building of the Hercynian epoch (the end of the Lower Triassic). All depressions of the Urals marginal trough are clearly asymmetric in form, but differ from each other in their history of development and the thicknesses and character of their stratigraphic cross sections.

The southernmost Belaya depression in the Chkalov (Oreburg)-Aktyubinsk area is filled with extraordinarily thick and structurally complex Upper Carboniferous, Permian and Lower Triassic sediments, totaling at least 9 to 10 kilometers in thickness. The Upper Carboniferous and the Lower Permian are represented on the eastern edge of the depression by gray-colored marine molasse and on the western edge by limestones; the Kungurian stage by thick salt-bearing strata; and the Upper Permian and Lower Triassic by a red-colored continental molasse that is quite coarse in the east, at the foot of the Urals, but changes sharply in rock composition near the Russian craton, from where tongues of marine sediments of the Kazania stage penetrate in the molasse. Middle Triassic continental sediments, which have been identified faunistically, are found only in the Chkalov-Aktyubinsk area. They rest unconformably on much older sediments in the crests of anticlines, sometimes directly on the Kungurian salt-bearing strata, which thus establishes exactly, at least for this part of the Urals, the time of completion of mountain building.

In more northerly parts of the Belaya depression, the thickness of sediments in the marginal trough decreases to about 6 kilometers. The central and western parts of the depression contain in the Sakmara and Arta stages formations of deep-sea siliceous silts and very large limestone reefs, in part of the barrier-reef type.

The southeastern parts of the Belaya depression contain linear folds overturned to the west; the central parts contain a complex system of salt-bearing anticlines, and the western part contains box-like block folds. Linear folds are absent in the northern part of the depression.

The Ufa-Solikamsk depression of the marginal trough is situated opposite the Middle Urals. Its structure is like that of the Belaya depression, but the thickness of its sediments is considerably less (2 to 3 kilometers).

Opposite the Northern Urals we find
ie Pechora depression, whose internal
tructure has not been sufficiently studied.
inally, the Vorkuta depression in the ex-
reme north is filled with a thick sequence
f land-derived sediments. Its lower mem-
ers consist of a flysch formation of Car-
oniferous and possibly of Sakmara age.
is topped by Arta marine molasse (2
ilometers thick), which in turn is overlain
y 5-kilometer thick coal-bearing strata of
ie Kungur stage and the Upper Permian.
he Korotaikha depression, which is situated
ven farther north and adjoins the Pay-Khoy
nticlinorium on the southwest, has a
imilar structure.

The depressions of the Urals marginal
rough are separated from each other by
orst-like ridges in which the uplifted bot-
om of the trough is exposed. The Belaya
nd Ufa-Solikamsk depressions are sepa-
ated by the Karatau horst; the Ufa-Soli-
amsk and Pechora depressions by the
olyudov Kamen horst; the Pechora and
orkuta depressions by the Chernyshev
plift, and the Vorkuta and Korotaikha
epressions by the Chernov anticlise.

aimyr and Severnaya Zemlya. The Taimyr
nd Severnaya Zemlya in the extreme north-
rn part of Siberia belong entirely to the
egion of Paleozoic folding. The more
recise age of Taimyr folding — whether
aledonian or Hercynian — is still not
ettled. The first edition of the tectonic
nap of the USSR showed the Taimyr and
evernaya Zemlya entirely as Hercynian.
he new edition reflects another point of
iew, namely that the southern zones of
he Taimyr belong to Hercynian folding and
he northern zone and islands to the Cale-
onian. This division is based on the fol-
owing considerations.

The northern part of the Taimyr con-
ists of a thick sequence of heavily dis-
ocated Precambrian metamorphic rocks
hat form folds overturned and thrust to
ie south. These Precambrian rocks
over a wide area, including not only the
orthern Taymir, but Bolshevik Island
nd the eastern coast of Oktyabrskaya
evolyutsiya Island. This crystalline zone
pparently represents the central part of
ie Taimyr folded zone.

To the northwest, Oktyabrskaya Revolyutsiya Island contains Lower Paleozoic geosynclinal formations that are plicated into a system of folds striking north and northwest. These formations are overlain unconformably by a red-colored molasse of Devonian age that resembles the Old Red of Western Europe. The Devonian molasse is dislocated only slightly and fills extensive interior depressions. All these relationships suggest that the northern zone of the Taimyr and the adjoining islands of the Arctic Ocean belong to the Caledonian epoch.

The southern zone of the Taimyr Peninsula, extending in a relatively narrow belt from the Yenisei estuary to the eastern end of the peninsula, is made of sedimentary geosynclinal formations of Lower and Middle Paleozoic age, as well as land-derived rocks of the Upper Paleozoic and volcanic sedimentaries of the Lower Triassic, resembling sediments of the same age in the Tunguska syncline. Structurally the southern zone of the Taimyr is a huge monocline dipping toward the Siberian craton and complicated by linear east-west folds. As a result, Lower Paleozoic formations are dominant in the northern part of this zone, Middle Paleozoic in the center and Upper Paleozoic in the south. The intensity of folding decreases from north to south. Sediments of the Tunguska series fill small interior depressions, which also strike east-west.

Areas adjoining the mouth of the Khatanga River are in a special position. There a series of salt domes, whose rock-salt cores may be of Devonian age, are found amid nearly flat Upper Paleozoic and Mesozoic rocks. This zone is intermediate between the Siberian craton and the Taimyr folded zone, and is called the Paleozoic Khatanga marginal trough. Over a large part of its area this trough is covered by a cratonic mantle of Mesozoic and Cenozoic age. The trough undoubtedly extends east and west over a long distance along the northern margin of the Siberian craton.

West Siberian Platform. The huge area of the West Siberian lowland is made up on the surface by flat-lying sediments of Quaternary and in spots of Neocene age. The geological structure of this area has

begun to be determined only in recent years as a result of geophysical surveys and borings. A number of geologists have proposed structural regions for the West Siberian lowland. Strictly speaking, however, all the proposed schemes are highly speculative and based to a large extent on guesswork.

It has been established by now that the structure of the West Siberian lowland consists of two stages. The lower stage, or basement, is made up of dislocated Paleozoic and pre-Paleozoic strata that are metamorphosed to varying degrees and invaded by intrusions. In the future we can expect to find both Caledonian cores and more recent Hercynian geosynclinal zones in this basement. So far we can say definitely only that the dislocations in the western part of the basement adjoining the Urals strike north-south as in the Urals themselves. It is also quite probable that in the southeastern part of the lowland the strike of the Paleozoic folds takes the form of a large, complex right-angle bend, in which the northeast strike of the Tom-Kolyvan folded zone can be easily traced. The upper structural stage consists of a typical cratonic cover of Mesozoic and Cenozoic sedimentary rocks.

In its central section the West Siberian lowland is distinguished by the great depth of the folded basement. The surface of the basement dips toward the center from the Urals in the west, from the Central Kazakhstan block, the Altai, the Tom-Kolyvan zone and the Caledonian formations of southern Siberia in the south and southeast, and from the boundary of the Siberian craton in the east. Deep borings reach the surface of the basement with relative ease in the outer sections of the platform, but in the center borings are still within the cratonic mantle at a depth of 3,000 meters, having reached only the Valanginian state or the Upper Jurassic. A number of deep depressions have been identified in the basement by geophysical surveys and borings. They include the Irtush synclie, which strikes northwest parallel to the northeast boundary of the Paleozoic block of Central Kazakhstan; the Ob-Taz synclise, in the northern part of the platform, and the Kas depression, in the southeastern section, opposite the Yenisei uplift of the Siberian craton.

In the Irtysh synclise the basement is submerged to a depth of 3,500 to 4,000 meters and the Cratonic sediments of the Mesozoic and Cenozoic attain a corresponding thickness. The basement lies at a depth of more than 4,000 meters in the center of the Ob'-Taz synclise, which opens north onto the Kara Sea and branches out north-eastward in the Pyasina depression, extending toward the Khatanga trough. In the Kas depression, according to geophysical data, the depth of the basement may be even greater.

The central part of the West Siberian platform, again according to geophysical data, contains the large Vasyugan anticlise, which separates the depressions discussed above. In the crest of the anticlise the basement is at a depth of 1,600 to 2,000 meters.

Borings in the western and southwestern sections of the platform have established that the basement is complicated by a system of graben-like depressions. These are filled with slightly dislocated land-derived coal-bearing rocks of the Triassic and the Liassic, whose lower horizons contain concordant intrusives, which may also be the roofs of basic rocks. This graben fill forms a sharp angular unconformity with the basement rocks and is invaded unconformably by the upper members of the Cratonic mantle, which here includes all sequences of the Middle and Upper Jurassic, the Cretaceous and the Paleocene. The rocks of the cratonic mantle of the West Siberian platform are predominantly land-derived, although the Upper Cretaceous and the Paleocene also contain siliceous formations of organic origin.

The dislocations of the cratonic mantle are most evident in its western part, adjoining the Urals. An example is the Berezovo uplift, a large ridge-like structure, striking 200 kilometers north and south parallel to the Urals with a width of 30 to 50 kilometers. The angle of dip of the nearly flat-lying limbs does not exceed one degree. The Berezovo uplift is bounded in the lower horizons of the cratonic mantle by a series of faults. To the west there is a deep graben. As we have seen, grabens striking north-south are a characteristic form of dislocation of the lower members of the mantle in the western part of the

tform. They are even found outside the tform, as the Chelyabinsk graben on the tern slope of the Urals.

The northeastern sections of the platm, around Ust-Port, contain large, tened, rather clearly outlined antines that consist of marine facies of the assic and Cretaceous and whose cores made up of Permian-Triassic redored formation resting unconformably Silurian dislocated limestones. The of the limestones is at a depth of about 00 meters.

The clearly defined Turgai trough ends southward from the southwestern t of the West Siberian platform and ns onto the Turan platform in the south. e Turgai trough is relatively shallow and rply asymmetrical. Its western limb s extremely gently and the cratonic ntle over a long distance from the godzhar hills is only dozens or at most ew hundreds of meters thick. The east- limb, on the other hand, dips relatively rply and the Paleozoic Basement is idly submerged from the direction of ntral Kazakhstan. In this connection the etaceous and Tertiary rocks of the craic mantle display a more complete atigraphic cross section and a greater kness (500 to 600 meters) here than in western limb. The pronounced strucal asymmetry apparently originated ing the geosynclinal period of developnt of this area and is determined by the sence along the eastern edge of the ugh of a zone of deep-seated fractures t separates the Hercynian folded sys-, striking north-south, from the Caleian folded structures of the western t of Central Kazakhstan, with their re complicated strikes.

The northern part of the Turgai trough complicated by the Kustanai transverse dle, located at the same latitude as the chetau uplift of Central Kazakhstan. hin the saddle the Paleozoic basement at depth of less than 100 to 200 meters.

The cross section of the cratonic manin the Turgai trough has much in comn with the cross section of the mantle he part of the platform adjoining the ls, but the Turgai section is less come. In both places the basement is disturbed by a system of grabens and depressions striking north-south and filled with coal-bearing rocks of Rhaetic and Lower and Middle Jurassic age. The main difference is that in the middle and southern sections of the Turgai trough the mantle rocks have been subjected to considerable inherited dislocations striking north-south, which have continued right into Quaternary times. These dislocations have determined many features of the geomorphology of the Turgai trough.

Turan Platform. The vast deserts, semideserts and piedmont oases of southern Kazakhstan and Central Asia, as well as the West Siberian lowland, are part of the epi-Paleozoic Eurasian craton.

We still lack adequate data to show all structural features of the surface of the Paleozoic basement of this area. However, available data point to rather sharp differences in the depth of the basement in various areas. In many parts of the Turan platform there are outcrops of the basement rocks. These outcrops include the Kyzyl-Kum hills (the Kuldzhuk-Tau, the Bukan-Tau and others), which are a western continuation of the subsiding ranges of the Tien Shan; the Sultan-Uiz-Dag uplift in the lower reaches of the Amu Darya; the outcrops of folded Permian and Triassic in the core of the Mangyshlak meganticline; the outcrops of folded Paleozoic and Triassic in the core of the Tuarkir uplift, and apparently the outcrops of Paleozoic magmatic rocks in the core of the Bolshoi Balkhan and in the Krasnovodsk peninsula. Elsewhere in the Turan platform the basement is covered by a cratonic mantle of Mesozoic and Cenozoic sediments. In the deepest depressions of the area north of the Aral Sea, the basement is at a depth of 1,300 meters or more. In the North Ustyurt trough, according to seismic data, the bottom of the Neocomian stage is at a depth of 3 kilometers, so that the folded basement would be at least at 5 to 6 kilometers' depth. It has been established that the basement of the Turan platform has a heavily dissected surface relief, which tends to distort structural details. The depth of the basement has not yet been determined in many places either by geophysical surveys or by borings. The tectonic map therefore shows the structure of the platform only by means of surface

contours of key beds of the cratonic mantle. These include the top of the Upper Cretaceous in the northern part of the platform and the bottom of the Sarmatian stage in the southwest.

The folded basement of the Turan platform consists of pre-Paleozoic and Paleozoic rocks. Parts of the basement include dislocated sediments of the Lower, Middle and possibly even of the lower members of the Upper Triassic, as in Mangyshlak, Tuarkir and the Lower Syr-Darya uplift. This circumstance led A. D. Arkhangelskiy to suggest that the Mangyshlak and Tuarkir sections of the basement might belong to areas of early Mesozoic folding. This view must now be rejected entirely. The Triassic stage of development of the earth's crust is intimately linked with the Permian in the Paleozoic folded areas of the southern and central parts of the USSR (the southwestern part of the Siberian platform, the Turgai trough and the Turan platform), just as it is intimately linked with the Upper Paleozoic stage in Precambrian cratons. The turning points in the development occurred in the period from the Middle Triassic to the Lower Jurassic. Therefore the term "Hercynian epoch of folding" must be extended in the USSR to include the Lower Triassic in the Urals and the Middle and possibly even the lower members of the Upper Triassic in Mangyshlak and other parts of the Turan platform.

The structure of the folded basement of the Turan platform is very complex and is still far from being fully known. It contains the deep-seated continuation of folded structures of the various tectonic zones of the Tien Shan. Structures of the Zeravshan anticlinorium of the southern Tien Shan continue westward in the outcrops of the Paleozoic in the Kyzyl-Kum and in the Sultan-Uiz-Dag. Geophysical and paleogeographic data suggest their further continuation through the Ustyurt in the area of the Buzachi Peninsula. This zone is apparently adjoined in the north by a deep trough filled with Upper Paleozoic molasse. These rocks outcrop on the northern slope of the Bukan-Tau in the Kyzyl-Kum and have been reached by borings at the foot of the northern scarp of the Ustyurt (south of the South Emba placanticline).

In the southwestern part of the Turan platform, the basement rocks are relatively older and lie at lesser depths, outcropping even in the Tuarkir, the Krasnovodsk Peninsula and the Bolshoi Balkhan. These rocks apparently include Silurian shales and various magmatic rocks which according to absolute-age determinations belong partly to the Precambrian and partly to the Middle Paleozoic. There is not sufficient basis for suggestions that some magmatic rocks of this area may be of Mesozoic age. Geophysical data show that the strike of the basement structures corresponds to that of the cratonic mantle, which is east-west in the Krasnovodsk Peninsula and the Bolshoi Balkhan, and northwest in the Tuarkir area. The eastern continuation of this part of the Turan platform apparently subsided considerably in Tertiary times in connection with the formation of the Kopet Dag marginal trough.

The western continuation of the Zeravshan anticlinorium was separated from the Tuarkir-Krasnovodsk area in the Upper Paleozoic and the early Mesozoic by a nearly east-west trough extending from the Mangyshlak to the south foot of the Sultan-Uiz-Dag. This trough was apparently asymmetrical in structure. T[illegible] greatest submergence occurred along the northern margin of the trough, where the accumulation fill was chiefly of the mola[illegible] type and of great thickness. Alone the upper members of the fill, of Permian an[illegible] Triassic age, attain a thickness of at least 8,400 meters in Mangyshlak. Rocks of the same type reach Tuarkir on the southern margin of the trough, where the fill i[illegible] much thinner and lies unconformably on the older rocks of the folded basement.

The Mangyshlak zone was apparently the largest, but not the only, zone of Upp[illegible] and Lower Paleozoic downwarping in the Turan platform. At that time residual intermontane troughs existed in several places and were filled with sediments of the molasse type. For example, borings have reached Triassic rocks in the folde[illegible] basement of the Lower Syr-Darya uplift.

The cratonic mantle of the Turan pla[illegible]form consists of two structural stages. The lower stage, extending from the Upp[illegible] Triassic to the Lower Jurassic, fills

ividual tectonic depressions in the sur-
e of the basement. This stage consists
a rule of dark clayey sediments that
tain coal seams in areas of continental
ies. These rocks attain a thickness of
00 meters or more, as in the area south
he Sultan-Uiz-Dag and at the southern
of the Chushkakul anticline. This for-
tion apparently also includes the coal-
ring Jurassic shales of the Fergana
nge, which attain a thickness of more
n 3,000 meters, and the thick lower
mbers of the Jurassic in the Bolshoi
khan.

The upper stage of the cratonic mantle, luding the upper members of the Juras-, the Cretaceous, Tertiary and Quater-y, does not differ from formations of same age in the mantle of older cratons. upper stage is separated from both basement and the lower stage by a ak and a sharp angular unconformity, ch sometimes reaches 30 degrees. The ks of the upper stage fill vast depres-ns that sometimes resemble typical clises (the Sarykamysh, North Kyzyl-m, and Chu depressions, and the North yurt trough) or form gentle uplifts, h as the Lower Syr-Darya uplift. It been established that the lesser dis-bances of the upper stage have generally erited the linear structure of the folded ement. These minor dislocations are nd in the area north of the Aral Sea, the ngyshlak Peninsula, the Kyzyl-Kum and ewhere.

The above-mentioned characteristics he tectonic disturbances in the cratonic ntle of the Turan platform (such as the t that they inherited the structure of the ement) are apparently true for all epi-rcynian cratons and account for certain des of difference between them and the er cratons formed in the Precambrian.

e Epi-Hercynian Craton of the Southern ropean Part of the USSR. The Northern ucasus foreland, the steppe section of Crimea and southern Moldavia contain one of deeply submerged Hercynian led structures that bear many points of emblance with analogous structures of Turan platform. This zone, recently ignated as the Scythian craton or plat-m, is still little known, but some of its ic features are beginning to emerge.

It is bounded in the south by the Alpide folds of the Caucasus, the Caucasus marginal trough and the Crimean mountains, and in the west by the folds of the eastern Carpathians.

The structure of the basement of this zone in the Northern Caucasus foreland is identical with that in the northern sections of the Turan platform. It consists of dark Paleozoic shales (a boring at Peschanokopskaya has established their age as Tournaisian on the basis of Foraminifera in an intercalated limestone bed), invaded by granitoid intrusions in some places (Stavropol' uplift). The depth of the basement varies. In the northern part of the zone it lies at about 1,500 to 2,000 meters. Similar depths have been measured in the area of the Stavropol' uplift. However, in the northern slopes of the Indolo-Kuban' and Terek-Caspian troughs, the basement is at a depth of 3,000 to 4,000 meters.

In the northern Crimea the basement of the epi-Hercynian craton was reached by borings at 1,200 to 1,800 meters in the crest of the Novoselovskoye uplift. There Jurassic sediments that vary sharply in thickness rest on dislocated limestones and slates.

The Donets Basin, which was regarded by the map compilers as a transverse marginal trough penetrating deep into the Russian craton, is closely linked with the Paleozoic folded formations of this zone. The Donets trough arose as a cratonic structure at the start of the Devonian (see above). During the epoch of Hercynian folding, i.e. starting in the Middle Carboniferous, its eastern part, adjoining the right-angle bend in the boundary of the Russian craton and the Paleozoic geosynclinal region, began to develop as a marginal trough. The trough was filled with a paralitical coal-bearing formation typical for that type of structure, which attained a thickness of more than 10 kilometers. The folds and faults of the exposed part of the Donets Basin have been thoroughly studied and described. It should only be noted that these structures die out toward the west along the strike of the Donets trough at the same time as the character of their formations changes and the thickness of Middle and Upper Carboniferous sediments is sharply reduced. No such dying

out of Donets Basin structures has been observed in the east. In that direction the coal-bearing formation has been traced by borings as far as the Stalingrad-Tikhoretskaya railroad. Farther east the surface of the Paleozoic suddenly submerges and the coal-bearing formation of the Donets Basin is apparently replaced by geosynclinal beds of dark shale that have been reached by borings at Belaya Glinka and Promyslovoye. These shales are indistinguishable from the rocks that have been reached by borings in the basement of the Northern Caucasus forland.

It is important to note that the eastern boundary of the coal-bearing formation of the Donets Basin coincides with a north-south gradient of gravitational anomalies and with a structural line that continues northward in the Stalingrad flexure and southward in the eastern margin of the Stavropol uplift, particularly in the obscuring intrusive bodies of the Mineralnyye Vody area. It is quite natural to assume that this line represents a zone of deep-seated fractures that have developed over a long period of time and cut through the southern part of the Russian craton and adjoining folded areas.

The mantle of the section of the epi-Hercynian craton that has been discussed here is made up of Jurassic, Cretaceous and Cenozoic sediments. Its thickness and the completeness of its stratigraphic cross section increase toward the centers of deep depressions. In uplifted zones the lower members belong to the Aptian, Albian or Cenomanian stage. In the northern Crimea, the cratonic mantle consists mainly of Cretaceous, Paleocene and Neocene sediments that form a system of broad brachyanticlinal and brachysynclinal structures.

Farther west the epi-Hercynian craton forms a wide protrusion in the Danube lowland (in the Walachian depression of Rumania), where it is bordered by the mountain ranges of the Carpathians and the Balkans. The basement rocks outcrop within the Dobruja uplift, where metamorphosed volcanically-derived sedimentary rocks of the Lower Paleozoic, Silurian and Devonian are plicated into a number of folds striking northwest.

The Dobruja marginal trough, situated north of the Dobruja uplift, is filled with Jurassic clayey and sandy beds reaching a thickness of 2,000 to 3,000 meters. Thi trough was formed at the same time as th lower members of the cratonic mantle of the Turan platform and the Turgai trough and can therefore by classified only quite arbitrarily as belonging to the final stage of the Hercynian epoch. Therefore the very structure of the trough can be compared only arbitrarily to that of a margin trough.

The northwestern Hercynian folded structures within the western oblasts of the Ukraine are covered by the outer zone of the Carpathian marginal trough, within which they form the hypothetical Dobruja "ridge."

Within Poland and the Vladimir-Volynskiy area the epi-Hercynian craton occupies once again a large territory, bounded on the south by the Alpide folds of the western Carpathians. This territo is separated from the southwestern margin of the Russian craton by the large Vistual marginal trough in the Paleozoic basement. The time of formation of this trough corresponds to the main stages of development of the Donets Basin in the Middle and Upper Carboniferous. The Vistula marginal trough is also filled with a coal-bearing formation, which is thinner and contains more limestone beds than the Donets formation. The outline o the Vistula trough and the structure of its northwestern continuation have yet to be determined. The northeastern limb, adjoining the Russian craton, is a gentle monocline covered with the thick Upper Cretaceous sediments of the Polish-Lithuanian synclise. The southwestern limb, adjoining the Paleozoic Swietokrzyz uplift, is complicated by faulting and gentle folds.

The age of the dislocations in the Paleozoic basement of the Polish lowland is greater than that of the more easterly sections of the epi-Hercynian craton. Th sequence of geosynclinal formations in th Polish lowland in effect ends with sedime of the Carboniferous age. The Permian rocks are already part of the cratonic mantle.

e Hercynian Folded Zone of Transbay-ia and the Amur Region. In south-tern Siberia, folded structures of Paleo-c (Hercynian) age make up large areas Transbaikalia and the Amur region.

In Transbaikalia, the Hercynian for-tions of Mongolia can be traced into forest lands beyond the Chikoi River. s zone is separated from the older olonovyy-Stanovoi anticlinorium by a tem of huge Mesozoic and Cenozoic ressions, such as the Chikoi and Ingoda ressions. Another such system of ng depressions separates the older iclinorium from the Mesozoic folded e of eastern Transbaikalia. This zone n area of widespread accumulation of k sandy and clayey sediments of Silurian Devonian age, containing intercalated enstones, jaspers and limestones. er crystalline rocks are limited in ex- in this area. Also limited are Car-iferous and Permian sediments, which mainly land-derived and fill small in-ior troughs. Rocks of the Middle and er Paleozoic are plicated into complex ls with a northeasterly strike and are aded by large granite intrusions, which er most of the forest lands beyond the koi River. The entire zone contains a ge number of longitudinal fractures that ves as conduits for Mesozoic extrusives Mesozoic ore-bearing granitic intru-ns. Some of these fractures also led to formation of Mesozoic and Cenozoic ressions, which are filled with coal-ring sediments and have the same type tructure as the depressions formed on folded basement of adjoining southern tions of the Siberian craton.

The Hercynian folded zone of the Amur ion is the margin of the Hercynian for-ions of Manchuria. It covers the left k of the Amur River, the Zeya-Selemd- watershed, and continues as far as the eya River. This zone, especially the eya block in the east, is made up of amorphic Precambrian rocks and Cale-ian granitoids. Large areas consist of dle Paleozoic (Silurian, Devonian and ver Carboniferous) formations of the synclinal type. The Paleozoic rocks plicated into a system of folds that ear to be wrapped around the older es. The Hercynian folded rocks are cut large number of large fractures which are associated with hypabyssal intrusions of Upper Mesozoic granite-porphyries and other magmatic rocks. The surface of the Paleozoic folded basement in the Amur region is covered by a mantle of unconsoli-dated Mesozoic and Tertiary rocks which fill large, gently dipping depressions, such as the Zeya-Bureya and Central Manchurian depressions.

The structure and the history of de-velopment of Hercynian folding in the Amur region are still far from being fully known. This is due in part to the inadequate geo-logical work carried out thus far in Manchuria.

Region of Alpide Folding in the South of the USSR

The USSR contains a small part of the northern margin of the Alpide geosynclinal region between the Carpathians in the west and the Kunlun in the east. An outer sys-tem of large anticlinal uplifts (meganti-clinoria), arranged in echelon, extends along this belt. The inner section, to the south, consists of a number of folded zones made up of anticlinoria and synclinoria and of ancient interior blocks whose folded basement consists of Paleozoic and older rocks. These interior blocks include the Macedonian-Rhodope, Lydian-Carian, and Galatian blocks. In addition, the inner zone contains two kinds of Neogene in-terior depressions: superimposed depres-sions bounded by faults (the Vienna, Great and Little Hungarian, Transylvanian, Thracian, and Araks depressions) and deep, apparently inherited troughs, such as the basins of the Black Sea and the southern part of the Caspian Sea.

South of the inner zone of the geo-synclinal region is a second system of outer anticlinoria, of which the anticlinoria of the Armenian Taurus and the Zagros are shown on the map.

Both zones of outer anticlinoria are accompanied along their boundaries with epi-Hercynian and older platforms by a chain-like system of asymmetrical mar-ginal troughs isolated from one another.

The anticlinal uplifts of the northern outer zone differ greatly in structure. The system starts in the west with the

anticlinorium of the Western Carpathians, whose inner core (including the Lower Tatras and adjoining mountains) must be regarded as the terminus of the meganticlinorium of the Eastern Alps, from which it is separated by the central part of the superimposed Little Hungarian depression. The next anticlinorium is that of the Eastern Carpathians. Crystalline rocks of the Marmaros block outcrop in the core of this uplift, and its eastern limb consists of a flysch formation of the Cretaceous and the Paleocene. The Eastern Carpathians do not constitute a system of large overthrust folds, as was believed earlier by some geologists. For the most part the folding is normal. Only along the boundary with the Carpathian marginal trough are the folds of the flysch zone along the eastern limb overturned and thrust toward the trough, with the displacement attaining 14 kilometers along some low-angle thrusts.

The meganticlinorium of the Southern Carpathians has an extensive core of complex structure, consisting of Paleozoic crystalline rocks and sediments. The meganticlinorium of the Balkan Mountains consists of three anticlinoria overturned to the north.

The Crimean anticlinorium has not been preserved in its entirety. Its southern limb and part of its core dip below the bottom of the Black Sea. Its eastern end on the Kerch Peninsula is bordered by a system of small folds in the Tertiary sediments.

The meganticlinorium of the Greater Caucasus is sharply asymmetrical. It is overturned to the south. In the western part the core consists of Paleozoic and Precambrian rocks, and in the eastern part of Jurassic rocks. The southern limb contains two synclinoria consisting of Jurassic, Cretaceous and Paleocene flysch beds. The eastern and western submerged ends of the Greater Caucasus (in the Taman and Apsheron peninsulas) contain domelike diapir folds.

East of the Caspian Sea we find the folded system of the Kopet-Dag (the Turkmen-Khorasan Mountains), whose northern margin (the Kopet-Dag range proper) is situated within the USSR. Its structure is complicated by folds overturned to the north. West of the main Kopet-Dag structure a system of gradually submerging folds branches off along an almost transverse southwesterly strike. (Many geologists also include the Bolshoi Balkhan uplift among the system of outer anticlinoria.) To the east we find the anticlinoria of the Paropamiz, the Hindu Kush and the Northern Pamir, all of which are arranged in echelon. The last named merges in the east with the folded zone of the Kunlun.

All the above-mentioned anticlinal structures of the northern outer zone were formed and uplifted in Oligocene and Neogene times. They were formed as a result of the gradual intensification of initially small uplifting movements originating in the geosynclinal troughs. These troughs were formed in the Alpide geosynclinal region at the start of the Jurassic and in part at the end of the Jurassic and during the Cretaceous. In their initial form the uplifts appeared almost simultaneously with the formation of the troughs themselves. For example, the initial uplift of the axial zone of the Eastern Carpathians has existed since the Lower Cretaceous: in the Crimea and the Greater Caucasus such uplifts appeared in the Upper Jurassic. Uplifting movements became more intense in Neogene and Quaternary times, when they were associated with volcanic activity (as in the Carpathians and the Caucasus). The enclosing troughs also date from that time.

The Northern Pamir occupies a special position in the system of outer anticlinoria of the Alpide folded zone. The Northern Pamir is part of a system of large young folded structures adjoining directly to the south and is separated from the Hercynian folds of the southern Tien Shan to the north by a belt of deep troughs, including the Tadzhik and Kunlun marginal troughs. In the structure of its Paleozoic cross section, the Northern Pamir is closely related to the Alai zone of the Tien Shan. The two structures are also closely related in terms of their Mesozoic history, during which the Northern Pamir was a large geanticlinal uplift.

The marginal troughs bordering the Alpide folded zone on the north also display differences of structure.

arpathian Marginal Trough. This trough as formed at the start of the Neogene long the boundary between the Eastern arpathians and the Russian Precambrian raton. In the course of its development he trough migrated toward the craton and ecame distinctly asymmetrical in form. he trough falls into two zones: an inner one, formed in the Lower Miocene on top f the folded basement and filled with thick alt-bearing and molasse formations, and n outer zone, covering the margin of the raton and filled with Tortonian and Sarnatian molasse. The inner zone is comlicated by disharmonic folds and overhrusts. The outer zone is disturbed by raton-type dislocations.

ndolo-Kuban and Terek-Caspian Marginal roughs. These troughs were apparently ormed in the Paleocene at the boundary of he Caucasus and the epi-Hercynian craton f the southern part of the European USSR. hese troughs are also asymmetrical but isplay less evidence of migration toward he craton. The deepest and youngest parts f the Terek-Caspian trough, for example, losely hug the eastern part of the northrn slope of the Caucasus. These strucural aspects of the Caucasus marginal roughs are related to the specific developnent of the Caucasus itself, particularly s asymmetry, with overturning of folds to he south, in the direction of the inner ather than the outer depressions.

opet-Dag Marginal Trough. This trough eparates the Kopet-Dag system from the uran platform. It also arose in the Oligoene and, judging from geophysical data, as a sharply asymmetrical transverse ross section. In the south the trough is eparated from the Kopet-Dag by system f overthrusts. In the axial zone of the rough, the top of the Cretaceous sediments es at a depth of 3,000 meters, according o seismic data.

Farther east the marginal troughs of he Alpide zone are found in front of the rc-shaped folds of the Northern Pamir and he Kunlun. Since Hercynian folding had een intense in this zone and Alpide orogeny egan relatively early, the structure of he associated marginal troughs differs rom that of the marginal troughs in the ertiary folded zone farther west. The narginal trough bordering the Pamir on the west is the eastern part of the extensive Tadzhik depression dating from the Lower Mesozoic. The time of the start of the formation of the marginal trough proper is therefore not quite clear. Some geologists assign it to the Jurassic, when the trough began to fill with rather thick land-derived and salt-bearing sediments, with which the salt tectonics of Afghanistan and the Kulyab area are associated.

Kunlun Marginal Trough. The Kunlun trough separates the Alpide folded zone from the westernmost bulge of the old Chinese craton — the Tarim block — but the trough developed mainly on top of the Hercynian basement, according to stratigraphic data. The stratigraphy of the accumulated fill, which consists mainly of continental and red-colored beds, has not yet been worked out adequately. According to some data, its lower section belongs to the Tertiary; according to other data, to the Mesozoic.

The Kunlun marginal trough connects with the trough at the western foot of the Pamirs through a narrow downwarp zone in the Alai valley, the point where the Pamirs and the Tien Shan come closest to each other. The Cretaceous and Tertiary sediments of the southern edge of this narrow zone are heavily dislocated, forming high fold mountains (the Peter I and Trans-Alai ranges). In other parts of the troughs bordering on the Pamir and the Kunlun, subsidence and the accumulation of coarse molasse are still continuing.

The inner zone of the Alpide geosynclinal region contains in the Lesser Caucasus the clearly defined Somkhet-Karabakh anticlinorium, whose core is made up of Middle Jurassic rocks; farther west is the Adzhar-Trialet folded zone with anticlinal cores of Cretaceous rocks and limbs of thick volcanic Eocene sediments. The Adzhar-Trialet zone then passes into the anticlinal zone of the Eastern and then the Western Pontus. South of the Somkhet-Karabakh anticlinorium is the Sevan synclinorium. Still farther south is the Miskhan-Zangezur anticlinorium, followed, on the other side of the Yerevan depression, by the Daralagez anticlinorium.

South of the anticlinal zone of the Northern Pamir is the complex synclinorium

of the Central Pamir, followed by the anticlinal zone of the Southern Pamir, which passes westward into the Hindu Kush and has a Precambrian core.

The structures of the inner zone of the Alpide belt were formed in the Mesozoic and the Paleocene. The Central Pamir synclinorium was closed off in the Upper Carboniferous, as were the synclinoria of the Lesser Caucasus and Asia Minor in the Oligocene. The Neogene saw the beginning of uplifting of large segments of the earth's crust, accompanied by the formation of deep interior depressions (those of the Rion, Kura and Araks rivers) and the deposition of thick sediments. The interior depressions that developed in the Neocene farther west, such as the Great and Little Hungarian depressions, absorbed almost the entire inner zone between the Carpathians and the Dinaric Alps. Remains of these depressions are found in the blocks of western Rumania, the Bakony Mountains and other places.

The formation of the Great Hungarian depression and of the Transylvanian depression to the southeast was accompanied at the end of the Neogene by large-scale faulting and intense magmatic activity, resulting in the formation of volcanic zones and small intrusions.

The large-scale uplifts of Neogene times were accompanied by the formation of the basins of the Black Sea and the southern Caspian. There is evidence that these depressions expanded in the Cenozoic, and some geologists regard them as contemporary geosynclines.

The Alpide geosynclinal region as a whole is a residual structure left over from the Paleozoic geosynclinal region that separated the Russian and African cratons. This geosynclinal region shrank during the epoch of Paleozoic folding when large parts were converted into cratonic areas. Paleozoic folding appeared late in the zone that separated the Alpide geosynclinal region from the Russian craton, ending in the Triassic and in some places perhaps even in the Jurassic, as in the Dobruja. In the Neogene the narrow Alpide geosynclinal region entered its final stage of development, reflected in the uplifting of large mountain ranges and the formation of marginal troughs and extensive interior depressions. The superimposed flatlying depressions of the Hungarian type can probably be regarded as structures of a period of transition to the cratonic stage of development, while the deep depressions of the Black Sea type can be regarded as structures that have not yet completed their geosynclinal development.

Regions of Mesozoic Folding in the East of the USSR

The vast areas of the northeast and the east of the USSR are part of the region of Mesozoic folding of the Pacific belt. There are three distinctive regions in the USSR: the Verkhoyansk-Chukchi region, the East Transbaikalian-Amur region, and the Sikhote-Alin region.

Verkhoyansk-Chukchi Folded Region. The region includes the huge territory extending from the Lena River (the eastern margin of the Siberian craton) in the west to the Chuckchi Peninsula in the east. It continues eastward into North America. This region is complex in structure. It contains a number of ancient inner blocks surrounded by systems of large folded zones.

The Verkhoyansk-Chukchi region displays a wide occurrence of a characteristic formation of land-derived rocks (sandstone and shales) known as the Verkhoyansk complex. The time of accumulation of this formation extended from the Upper Carboniferous to the Middle Jurassic. Its thickness varies, attaining 8 kilometers in the Verkhoyansk Range.

The central part of the Verkhoyansk-Chukchi folded region contains the system of ancient blocks that were once designated as the Kolyma craton.

The largest of these blocks is the Kolyma block in the extreme west. To the east is the Omolon block, separated from the Kolyma block by the Omolon trough. Farther east, directly adjoining the Kamchatka zone, is the small Taygonos block, separated from the Omolon block by the Gizhiga trough.

The folded basement of the Kolyma block consists of a series of Paleozoic

nestones (up to and including the Lower rboniferous), among which Archean etamorphics and thick, land-derived beds the Proterozoic to the Lower Cambrian) outcrop on the right bank of the Kolyma ver. These ancient rocks are plicated o a series of folds striking north and rthwest (Moma anticlinorium).

The deposition of the Verkhoyansk mplex was accompanied in the Kolyma ock by the accumulation of relatively in limestone beds, reaching a thickness 1000 meters. In the northwestern secn (the Alazeya River basin) of the Kolya block, basic and acidic volcanic rocks cumulated during the Jurassic. Upper leozoic and Mesozoic beds are only ightly disturbed within the Kolyma block. s southwestern section contains the large ryanka depression, filled with a thick al-bearing formation of Jurassic and etaceous age (several thousand meters thickness), which has been almost unuched by folding. The upper horizons of is formation may be of Tertiary age.

The Omolon block shows rather wide currence of Archean slates and gneisses, vered by red-colored and volcanicallyrived Upper Devonian beds (2000 meters ick), predominantly land-derived Carniferous rocks (several hundred meters ick), and finally a thin mantle of fragental Triassic and Jurassic rocks. The oss section of the Omolon block lacks posits of the Cambrian, Ordovician, lurian, Lower and Middle Devonian, as ell as deposits more recent than the rassic. Over long periods of geologic me this block must therefore have been area of sustained emergence and eroon. The Paleozoic and Mesozoic mantle the Omolon block is only slightly disrbed. It forms a system of very gentle pressions and uplifts, which is however oken up by faults in a number of places.

The Kolyma and Omolon blocks are parated by the deep Omolon trough, which filled with the land-derived upper memrs of the Verkhoyansk complex, extendg from the Middle Triassic to the Lower rassic and attaining a thickness of 2000 eters.

The Taygonos block in the east is parated from the Omolon block by the Gizhiga trough. These structures resemble their western counterparts except that the eastern structures have been affected more heavily by Kamchatka folding and have been invaded by Mesozoic granitoid intrusions.

The Siberian craton is separated from the Kolyma block by a system of Mesozoic folded structures. In the western part of this system is the large right-angled Verkhoyansk arc. It consists predominantly of Permian and Lower Triassic rocks of the Verkhoyansk complex. In the extreme north (Kharaulakh anticlinorium) and the southeast (Setta-Daban anticlinorium) of the Verkhoyansk zone, the cores of the large uplifts contain limestones, dolomites and marls of Lower and Middle Paleozoic age, attaining a thickness of 5,000 to 6,000 meters in the Setta-Daban. Outcrops of the ancient Paleozoic basement show virtually no evidence of magmatic activity, except for occasional trap rock (gabbro-diabase) dikes that may have intruded at the boundary of the Permian and the Triassic. In general the Lower and Middle Paleozoic rocks are plicated into simple, gentle folds, complicated by large longitudinal fractures. The time of folding apears to have been the Middle Carboniferous. The Verkhoyansk complex within the Verkhoyansk folded zone also forms a system of simple and often rectilinear folds, with flattened arches and steeply dipping limbs. The Verkhoyansk folded zone shows limited evidence of magmatic activity, which appears to have been much more pronounced in the zones adjoining the east.

The Verkhoyansk zone is separated from the Siberian craton by the Verkhoyansk marginal trough, a huge depression bordering the Siberian craton on the northeast. It extends west of the Verkhoyansk Range, first along the valley of the Lena River, then along the Aldan River. The Verkhoyansk marginal trough penetrates deep into the Vilyui synclise at an acute re-entrant angle. In the east, the trough is closed off in the middle course of the Aldan River. In the north it connects with depressions that are cut by the lower courses of the Anabar and Khatanga rivers. These depressions may also be Mesozoic marginal troughs. The Verkhoyansk marginal trough is filled with a thick, partly coal-bearing molasse formation of Upper Jurassic and Lower Cretaceous age,

attaining a thickness of 3,500 meters and passing westward into similar sediments of the Vilyui synclise, where the thickness is considerably less. On the slopes of the Anabar block and in the northeastern part of the Aldan shield, the thickness of this formation is reduced to a few hundred meters.

The Verkhoyansk marginal trough merges in its central section with the trough of the Vilyui synclise, meeting it at a right angle. The junction has produced a very deep depression, whose cross section consists, on top, of Upper Cretaceous sandy and clayey sediments reaching a thickness of 1,000 meters.

The inner zone of the Verkhoyansk marginal trough contains large linear folds, while the outer zone, adjoining the craton, contains local dome-like and brachyanticlinal uplifts.

To the east of the marginal Verkhoyansk zone is the large Yana synclinal zone, which is separated by the Taskhayakhtakh anticlinorium from the Zyryanka depression of the Kolyma block and merges in the southeast with the Indigirka-Kolyma synclinal zone. This system of synclinoria is filled with the middle and upper members of the Verkhoyansk complex, including the Triassic and partly Lower and Middle Jurassic, which reach a thickness of 4,000 to 5,000 meters. The Jurassic members reach their greatest development in the northeasternmost synclinal troughs at the boundary of the Taskhayakhtakh anticlinorium. There Jurassic shales, reaching a thickness of 3,000 meters, have been heavily dislocated and invaded by Middle Jurassic granodiorite intrusions that form a clearly defined belt several hundreds of kilometers long.

In the southeast the Indigirka-Kolyma synclinal zone is adjoined by the Okhotsk inner block, which in turn is separated from the Aldan shield by the South Verkhoyansk synclinorium. Structurally the Okhotsk block resembles the Omolon block in many respects. Both were broken up during the period of accumulation of the Verkhoyansk complex and reduced in size. The ancient structure of the folded basement is visible through the covering mantle. The north and northwest sections show wide occurrence of distinctive block faulting that has produced a system of flat blocks of nearly horizontal beds of the Verkhoyansk complex separated by narrow linear grabens striking in various directions and filled with Permian and Triassic sediments.

The Taskhayakhtakh anticlinorium and its northeasterly continuation, the Polous anticlinorium, enclose the Kolyma block on the west and north. These are relatively narrow anticlinal systems that have been disturbed by a large number of longitudinal faults. They are filled with Paleozoic limestone beds.

It should be noted that the Cambrian sediments of the Taskhayakhtakh, Setta-Daban and Kharaulakh anticlinoria are everywhere represented by limestone beds that resemble the formations of the northern part of the Siberian craton both in the type of cross section and in thickness. This has prompted a number of geologists to suggest that during the Lower Paleozoic the Siberian craton covered large areas of the western part of the Verkhoyansk-Kolyma region that were later denuded and then developed geosynclinal conditions at the start of the epoch of formation of the Verkhoyansk complex. These very interesting suggestions, which are closely associated with the view that the process of cratonic development can be reversed, are still not sufficiently supported by reliable data.

To the northeast of the Kolyma and Omolon blocks we find a folded system striking southeast and almost east-west. Immediately adjoining the ancient blocks is a group of synclinoria of the Oloy depression, which are filled with thick volcanic and land-derived Jurassic beds. This synclinal belt is an eastern branch of the Verkhoyansk folded zone. Farther to the northeast we find a system of anticlinoria extending to the Chukchi Peninsula, of which the largest are the Anyuy and Chukchi uplifts. The Anyuy anticlinorium consists of land-derived beds of the Verkhoyansk complex, among which there are outcrops of small cores of older formations. The Chukchi anticlinorium has cores of Precambrian metamorphic rocks and Lower Paleozoic volcanic sediments. Beds resembling the Verkhoyansk complex in structure and age are also widespread. Here, in the extreme northeast, as on the

rgins of the Kolyma block, Mesozoic in-sions are widespread.

t Transbaikalian-Amur Folded Region. s region forms a narrow belt extending m the Shantar Islands in the northeast to tral Mongolia in the southwest. Nearly geologic systems are represented in structure of this region. The most espread are Middle Paleozoic sediments he geosynclinal type, consisting mainly ,500-7,000-meter-thick land-derived ks, intercalated with heavily altered ic extrusives and limestones. These s have been intensely dislocated and, he western sections, have been invaded large concordant intrusions of granites, rites and gabbro. Coarse fragmental iments of marine and continental origin umulated in the Upper Paleozoic and at start of the Mesozoic (up to the Middle assic), a period which is also associated h intensive volcanic activity. Some parts he cross section of the accumulated ies (as the Triassic of the Shilka River) w great structural similarity with the rkhoyansk complex of northeastern ia. The rocks of this epoch accumulated distinctive residual geosynclinal troughs e East Transbaikalian geosynclinal zone l the Upper Amur geosynclinal zone), ere they were plicated into a system of atively simple folds striking northeast. e Mesozoic folds are invaded by small nite bodies. In a number of places in Upper Amur region there is a close eal relationship between these granites l large fracture zones that cut through h Paleozoic and Mesozoic folded uctures.

The Mesozoic synclinal troughs are arated by uplifts consisting of Archean, oterozoic and Paleozoic formations. ese include the Aga, Argun and Dzhagda-kuringra uplifts. Within these uplifts Meszoic formations are thin and only ightly folded.

A typical characteristic of the East ansbaikalian-Amur folded region is the le occurrence of faults of varying sizes, iking ENE. Such a fracture zone is found, example, along the boundary between region of Mesozoic folding and the thern limb of the Yablonovyy-Stanovoi iclinorium. These fractures are associ-d with the formation of young depressions, filled with the Turga shales and coal-bearing sediments ranging from the Upper Cretaceous to the Cenozoic, and with intensive volcanic activity resulting in basalt flows at the start of Quaternary times.

On the margins of the folded region, along its boundaries with the Reefian Yablonovyy-Stanovoi anticlinorium and the Paleozoic Bureya block, there are large troughs (the Upper Zeya-Uda and Amur-Zeya troughs) filled with distinctive, partly coal-bearing molasse of Upper Mesozoic and Tertiary age. These depressions may be regarded arbitrarily as marginal-trough-type structures.

Sikhote-Alin Folded Region. This region is situated between the Paleozoic Bureya block in the west and the coast of the Sea of Japan and the Tatar Strait in the east. Toward the north, in the basin of the Tugur River, it joins the East Transbaikalian-Amur folded region, and toward the south, it is submerged under the Sea of Japan, reappearing again in Korea.

The Sikhote-Alin region consists of several large anticlinoria and intervening synclinoria. Pre-Paleozoic metamorphosed and dislocated rocks outcrop in the crest of the Khingan-Bureya anticlinorium and the main anticlinorium of the Sikhote-Alin. Middle Paleozoic formations are found in a limited number of places. The Upper Paleozoic is well developed, attaining a thickness of 5,000 to 6,000 meters, in the form of a flysch-like series with intercalated basic lava beds. Granitic intrusions took place at the end of the Paleozoic in the Grodekovo zone in the southwest. During the Triassic and the first half of the Jurassic, the anticlinoria continued to grow and thick flysch-like sediments resembling the Verkhoyansk complex of northeastern Siberia continued to accumulate on the margins of the anticlinoria and in the synclinal troughs. Starting in the second half of the Jurassic and continuing into the Cretaceous, volcanic activity became intense in the Sikhote-Alin folded region, producing an accumulation of thick beds of basic and acidic volcanic rocks, especially in the main synclinorium of the Sikhote-Alin. Granitoid intrusions forming several complex blocks are also assigned to that period.

The Mesozoic sedimentary and volcanic rocks of the Sikhote-Alin folded region are heavily dislocated. The folds are often heavily compressed and broken by longitudinal faults, retaining a general north-south strike.

The time of completion of folding coincided with the formation and development of the Bureya marginal (?) trough, a small but quite distinctive depression separating the Bureya block of Paleozoic granites from the adjoining Mesozoic folded structures. This trough is filled with a thick Upper Mesozoic and Tertiary coal-bearing formation that is in many respects typical of marginal troughs.

The Verkhoyansk-Chukchi, Sikhote-Alin and East Transbaikalian-Amur regions of Mesozoic folding of the Pacific belt have both points of resemblance and of major differences.

The most important point of resemblance in the structure and history of the development of these three regions is the existence at the end of the Paleozoic of definite tectonic conditions leading to the formation of land-derived sediments of the Verkhoyansk-complex type. These conditions existed in the Verkhoyansk region in Carboniferous, Permian, Triassic and Jurassic times, and in Transbaikalia and the Sikhote Alin from the Permian to the Jurassic. The similarity of development in the Upper Paleozoic and the Mesozoic is a distinctive feature of all zones of Mesozoic folding. The second stage, starting in the Middle Jurassic and continuing for different lengths of time in various regions, was accompanied by intensive magmatic activity in the form of intrusions (granitoids) and extrusions.

Differences in structure and development are also quite substantial among the three regions of Mesozoic folding. The Verkhoyansk-Chukchi region is eroded relatively slightly. Its lower structural stages are deeply submerged. Sediments of Lower and Middle Paleozoic age outcrop very rarely, mainly in marginal anticlinnoria where their formations differ little from the cratonic type. The Verkhoyansk complex, which normally takes linear structural forms, is very widespread.

A similar picture is found in the Sikhote-Alin region, including the Lower Amur, except that the Paleozoic is developed much more extensively there.

Eastern Transbaikalia and the Upper Amur region look quite different. There Paleozoic and older rocks, forming various kinds of uplifts, are most widely developed, and analogues of the Verkhoyansk complex are found only in narrow, sharply reduced troughs, often only in the form of isolated strata. Typical of this zone are the emergence of the lower structural members, the heavy dissection and consequent the great depth of the erosional cross section. The reconstruction of Mesozoic folded structures and the exact determination of their boundaries are therefore very difficult in Transbaikalia and the Upper Amur region. In this connection some geologists are inclined to classify this region as that of a separate type of geosynclinal trough, differing from the regions of Mesozoic folding in northeastern Siberia and in the Sikhote-Alin. It is quite possible that the East Transbaikalian Amur region should be regarded as an area of Hercynian folding that was later disturbed by Mesozoic movements and magmatism similar to the Chinese Paleozoic structures farther south.

Region of Cenozoic Folding of the Pacific Belt

Kamchatka Folding

The extreme eastern part of the USSR in the Anadry region, Kamchatka, the Okhotsk coast, the Kurile island arc, Sakhalin and the eastern margin of the Sikhote Alin, contains the most recent geosynclinal formations associated with Cenozoic folding of the Pacific belt.

Outer Belt of Cenozoic Folding. Along the boundary between the regions of Mesozoic folding and the more recent Cenozoic structures we find a gigantic volcanic belt, the first one to be classified as an independent self-contained structural zone. This belt extends in a zone 100 to 200 kilometers wide from the southern Chukchi Peninsula to the left tributaries of the Anadry and on to the Taygonos Peninsula in the southwest. There it is interrupted by a bulge of the Mesozoic inner block.

e volcanic belt reappears north of zhiga Bay and can be traced in a con- uous belt along the coast of the Sea of hotsk to the Dzhugdzhur range. There strike changes abruptly to east-west d the volcanic belt disappears in the uthwestern part of the Sea of Okhotsk, appearing once again on the mainland ast in the area of Sakhalin Gulf and con- nuing southward along the west coast of tar Strait as far as Ol'ga Bay.

Along its entire length the volcanic lt surprisingly by retains unchanged all s structural features. It is made up edominantly of volcanic rocks of Senonian d Tertiary age that display a peculiar ythm of deposition, starting with basic intermediate lavas and ending usually ith acidic flows. The thickness of the trusive beds attains several hundreds of eters, and in some places thousands of eters. The volcanic rocks are separated om the underlying formations by a sharp gular unconformity.

The rocks of the volcanic belt are only ightly disturbed. Along the coast of the atar Strait they are plicated into a sys- m of relatively gentle folds, following e regional strike. In several places on e Okhotsk coast the volcanic beds lie orizontally. In many places they are ulted and invaded by small intrusions of naritime" granitoids dating mainly from e Eocene.

The outer volcanic belt can be regarded s the product of the initial stage of deposi- on in geosynclinal troughs of the Cenozoic lding of the Pacific zone. Cutting sharply rough the various structural elements of esozoic folding in northeastern Siberia, etween the Dzhugdzhur Range and the asin of the Anadyr River, the volcanic belt llows a zone of large tectonic seams eparating the newly arisen geosynclinal egion from the west. From this point of iew, both the position and the structural atures of the volcanic belt follow ex- ected lines. The problem of the existence f similar outer belts accompanying the rmation of older geosynclinal areas has ot yet been raised. It is quite possible at the existence of this belt is peculiar the structure of the Pacific hemisphere.

oryak-Kamchatka Folded Region. This region has a non-homogeneous structure. It consists of several anticlinoria separated and covered by various kinds of troughs.

In the southern part of the Central Kamchatka Range we find an exposed section of the Central anticlinorium of Kamchatka, consisting of gneisses and intensively dislocated slates of the Pre-cambrian and the Lower Paleozoic. The limbs of the uplift are made up of presumbably Paleozoic land-derived and volcanic rocks, plicated into compressed folds striking north-south and invaded by Mesozoic granitoid bodies.

Along the east coast of Kamchatka extends the East Kamchatka anticlinorium, whose core consists of Upper Cretaceous rocks and whose limbs are made up of Paleocene sediments plicated into narrow linear folds striking northeast and invaded by Paleocene granitoid intrusions. The central part of this anticlinorium contains ultrabasic intrusions that penetrated along large longitudinal fissures.

Situated farther northwest and arranged in echelon is the Koryak anticlinal zone, which is associated with the western and central sections of the Koryak upland. The outcrops in the core of this large uplift consist chiefly of volcanic formations of Lower and Middle Cretaceous as well as of Paleogene age. The northern part of the anticlinorium is complicated by large synclinal folds filled with Paleogene and Noegene rocks. Like the East Kamchatka anticlinorium, the central part of the Koryak anticlinal zone contains ultrabasic intrusions.

Finally, in the northwest, and arranged once again in echelon with respect to the preceding structure, is the Mayn anticlinorium, situated in the Penzhina, Mayn and Pekulney mountains. Its core consists of a folded sequence dating from the Middle and Upper Paleozoic, the Triassic, Jurassic and Lower Cretaceous, overlain unconformably by more recent folded rocks of Upper Cretaceous and Paleogene age. The core of the Mayn anticlinorium, like the two preceding uplifts, contains many ultrabasic intrusions associated with a system of large fissures.

West of the Mayn anticlinorium lies

the large Penzhina depression, coinciding topographically with the Anadyr-Penzhina surface depression. It is filled with thick beds of Neogene sediments that form a mantle over Upper Cretaceous and Paleocene rocks plicated into linear folds.

In the Penzhina depression the Neocene is represented by an essentially land-derived formation partly of marine and partly of continental origin. It forms a system of brachy-folds striking generally northeast.

The West Kamchatka trough is located on the southwest coast of Kamchatka. This depression is filled with the thick beds of a continental coal-bearing formation of Pliocene age, resting unconformably on intensively dislocated sediments dating from the Upper Cretaceous, Paleocene and Miocene. The Pliocene beds are gentled folded, with the dominant dip toward the west. Pre-Neogene rocks usually outcrop in the cores of these folds.

The central section of Kamchatka is occupied by the Central Kamchatka depression. It lies on top of the folded structure of the Central anticlinorium and other large uplifts of the peninsula. The depression is filled with Miocene and Pliocene beds covered by a thick mantle of Quaternary and contemporary andesites, andesite-basalts and basalts. The Pliocene and Miocene formations consist of relatively lightly dislocated land-derived beds of marine and continental origin reaching a thickness of 2,000 meters. In the present watershed of the Central Kamchatka Range, these rocks are replaced by more recent volcanic formations. The Miocene and Pliocene rocks form broad, gentle synclines complicated by brachyanticlinal folds, whose cores contain occasional outcrops of the lower structural stage dating from the Upper Cretaceous and the Paleocene. The Miocene and Pliocene rocks also have been invaded by small granitoid intrusions.

The Koryak-Kamchatka folded region displays active contemporary tectonic activity in the form of intensive recent vertical movements, dislocation of Quaternary deposits, volcanism and earthquakes.

Sakhalin. The Kamchatka folded zone connects through the Kurile island arc directly with the folded structures of Japan in the eastern zone of Hokkaido. Together with these structures Kamchatka forms a separate system of Cenozoic folding of the Pacific belt, distinguished by contemporary tectonic activity and volcanism.

Sakhalin occupies a special position with respect to that system. In differs from Kamchatka in the character of its Tertiary cross section, an absence of contemporary volcanism and the reduced degree of tectonic movements. These sharp differences between Sakhalin and adjoining Cenozoic folded regions has long puzzled geologists working on the Far East. It has even been suggested that Sakhalin should be regarded as a marginal trough.

Sakhalin contains two large anticlinoria separated by an intermediate synclinorium. The cores of the anticlinoria contain outcrops of thick beds of Proterozoic and, possibly, of Paleozoic crystalline schists and slates of the Eastern and Sasunay ranges, as well as outcrops of Middle Paleozoic ophiolitic, spilitic and shale formations and Upper Paleozoic clayey and siliceous shales, jaspers and limestones, similar to formations of the same age on Honshu (Japan). All these formations have been intensively disturbed and form a system of compressed folds striking north-south. Their eroded surface is overlain by thick beds of Cretaceous and Tertiary land-derived rocks. These beds contain slight evidence of submarine volcanism and widely developed oil-bearing facies (in the east) and coal-bearing facies (in the west). Young intrusive rocks are relatively limited on Sakhalin. Small granitoid bodies and alkaline rocks occur only in a few places. The Tertiary sediments on the limbs of the two anticlinoria and of the central synclinorium are plicated in a system of simple folds that take the form of domes in the northern parts of the island.

The problem of the structural position of Sakhalin cannot be settled definitely until we have data on the geological structure of the bottom of the Sea of Okhotsk.

If we draw analogies between Sakhalin and the folded structures of other zones, a

mparison suggests itself above all with e Verkhoyansk anticlinorium during the me of the accumulation of the upper memrs of the Verkhoyansk stratigraphic comex. The sediments of both structures nsist mainly of land-derived formations, splay little evidence of magmatism, and semble each other in the type of tecnic disturbances.

CONCLUSION

This explanatory note has outlined the inciples that guided the compilers of the ctonic map of the USSR and has briefly scribed the main structural features of e various tectonic regions. In the process large number of important tectonic ructures have undoubltedly been menoned too fleetingly or in some cases not all. This is due both to the brevity and e purpose of the note, which is designed ly to help the reader interpret the map ther than explain it in all its details.

The compilation of a tectonic map of e USSR, even at such a relatively small cale as 1;5,000,000, has required the eneralization of the studies of a huge umber of Soviet geologists who have inestigated the structure of the earth's rust within the territory of the USSR and djacent countries. The map, covering a ery large and structurally diverse secon of Eurasia, represents above all a asis for drawing theoretical conclusions bout principles of tectonic development. nyone who studies the location and terrelationships of structures of different ges and different types on the map can nderstand the movements of the earth's rust in its various sections.

Study of the map enables us to draw a umber of conclusions about the make-up nd origin of the principal tectonic strucures. The first thing that strikes the eye the rectilinear character of many oundaries between structures of various egions and the angularity of outlines. hese aspects are evidence of the great ole played by deep-seated fractures in e earth's crust that are not always reected in the form of surface faults. Also vident from the map are differences in e history of tectonic development of the acific and Atlantic segments of the earth's rust. This important fact runs counter to the idea of universal tectonic cycles. The map also clearly disproves the hypothesis under which each craton is surrounded by concentric folded systems of increasingly younger age, a hypothesis that until recently was used to lay actual plans for the search for oil and other minerals.

The map shows clearly the linearity of folded systems that hug the edges of cratons, and the reduction and even partial disappearance of such linearity in the interior of geosynclinal regions. Several interesting conclusions suggest themselves with respect to the tectonic principles of magmatism of varying composition in folded systems of varying ages. The tectonic map of the USSR can serve as a reliable base for working out many problems in theoretical tectonics, whose solution is often attempted without regard for the phenomena and relationships that are actually present in nature.

At the same time the map can apparently be of practical importance even at the present stage. It can be used as a base for compiling various kinds of metallogenic maps and mineral-forecast maps. The experience of all geological institutions engaged in the compilation of metallogenic maps has shown that such maps should contain data on the age of folding, the distribution of various structural stages in each zone of folding, the position of specific tectonic forms (folds, faults), and finally, the structural position, age and composition of intrusions. It so happens that the very same data make up the content of the tectonic map. It is not surprising therefore that the 1952 édition of the tectonic map of the USSR was widely used in various institutions in attempts to formulate principles that govern the distribution of various minerals. The new tectonic map should be even more useful in this respect because it shows the position of intrusions of various ages and composition.

The practical importance of a tectonic map as a base for the compilation of metallogenic and mineral-forecast maps will undoubtedly increase as its scale increases. Experience with the present edition has shown that for the solution of many theoretical and practical problems it will be necessary and is already quite possible to compile large-scale tectonic maps of at

least 1:2,500,000, at first for separate regions of the USSR and then for the country as a whole. Compilation of such maps will require further refinement of the principles of tectonic analysis used in the 1:500,000 map.

Specifically, in addition to showing the age of a folded structure and its structural stages, it will be necessary to work out and show on the map a classification of major tectonic forms in terms of their character of development. We know even now that there can be great differences in geosynclinal troughs, geanticlinal uplifts and other tectonic forms of this magnitude dating from the same age. Each of these structural categories can be subdivided into types differing from each other in general morphology, in the sequence of characteristic formations, magmatism, the character of small dislocations, and, finally, the history of development and, consequently, the metallogenic conditions. In such a classification structural forms of the same type may be found in folded structures of different ages.

Large structures of cratonic areas, such as shields, anticlises and synclises, could apparently also be subdivided into types based on the history of development.

Formulation of principles that guide the distribution of tectonic forms of various types both in time and in space would make it possible not only to clarify many as yet obscure aspects of the tectonic development of the USSR but to provide a more reliable base for the compilation of metallogenic and mineral-forecast maps.

The compilation of more detailed tectonic maps of the USSR would also require the solution of a number of problems relating to an understanding of the structure and the history of the tectonic development of the USSR.

In the first place, it will be necessary to show on the map the character and intensity of recent and contemporary tectonic movements, which are of great importance in the formation of surface relief and to a certain extent also determine the seismicity of the territory of the USSR. We know that these movements are not related directly to the age of folding of any given area and consequently are not reflected in the conventional symbols used in the present edition.

Secondly, it will be necessary to analyze available data on the deep-seated structures of the folded basement of cratons and to try to show the strikes of these structures and the lines of buried fractures making wide use of geophysical data in this connection.

Thirdly, it will be necessary to work out a rational classification of fractures, which would be of great importance in the understanding of the principles that guide the distribution of mineral deposits.

Fourthly, the new tectonic maps should show the results of tectonic studies of the bottoms of the seas and oceans off the coasts of the USSR. Specifically, an understanding of the relationships between the Polar Urals and the Taimyr requires data on the structure of the bottom of the Kara Sea; and correct representation of the tectonics of the northern coasts of Siberia requires data on the tectonics of the Lomonosov submarine range, which was discovered and mapped by Soviet ice-floe stations. Solution of the problem of the tectonic position of Sakhalin will require use of the geological and geophysical data on the tectonics of the Sea of Okhotsk that were obtained during the oceanographic work of the Academy of Sciences USSR on the ship Vityaz. The discovery of large submarine ranges striking north-south on the bottom of the South Caspian depression also changes our present ideas about the tectonic nature of that depression and the adjoining areas. All this shows that tectonic analysis of the bottom of seas and oceans will be an inseparable part of any future compilation of a tectonic map of the USSR.

It should however be noted that the territory of the USSR, in spite of its size, will be inadequate in some cases to clarify general principles of the structure and development of the earth's crust. Many problems can be settled only by analysis of material on a world scale.

Therefore, in addition to compiling larger-scale tectonic maps of parts of the USSR, we should try to compile tectonic

aps of even larger areas, even if they ust be at small scales. At the present me, in addition to the tectonic map of the SSR, there are tectonic maps of the nited States, Canada, Africa and other eas, which were compiled on the basis other principles. The 20th International eological Congress in Mexico City in 956 adopted a resolution on the compila- on of a world tectonic map at 1:10,000,000. The Soviet Union has been asked to take charge of the compilation of this map. In the light of this assignment our next task should be the compilation of a tectonic map of Eurasia and the verification, on the basis of material relating to these two continents, of the possiblity of further refining the principles of tectonic analysis used in the compilation of the tectonic maps of the USSR.

SOME STRUCTURAL CHARACTERISTICS OF MOBILE TECTONIC BELTS [1]

by
V. A. Nikolaev
• translated by Mark Burgunker •

ABSTRACT

The present paper is an exposition of the author's views on a series of problems in the structural development of the mobile belts in the Earth's crust. The tectonic and facies characteristics by which the fundamental components of the mobile belts - geosynclines and geanticlines - are distinguished, are presented in outline. The laws that govern the evolution of these components in space and time are also indicated.

INTRODUCTION

The interconnection and interaction of tectonics, sedimentation, magmatic activity, and vein mineralization are generally accepted as an integral part of the present-day understanding of the long and complex developmental history of geosynclines, or, more generally, of the mobile belts of the crust. Certain laws which manifest themselves in a persistent, periodic manner, have been discerned as being fundamental to this entire ensemble of geologic processes; these laws, however, also hide - to a certain extent - the over-all direction and the irreversible nature of the many faceted evolution of mobile belts of various ages. This masking of the irreversible nature of geologic processes explains the persistence with which geologists use the term "cycle" to describe a great variety of geologic processes - tectonic, magmatic, hydrothermal - of varied duration and varied dimensions in space, that characterize one aspect or another of the development of a mobile belt, in whole or in part. The present author, for example, distinguished the following cycles in Central Asia as early as 1928: (a) the Precambrian, (b) the early Paleozoic (Caledonian), (c) the late Paleozoic (Variscan) and (d) the Mesozoic (Alpide). These cycles occurred in the Tien Shan ranges and the Pamirs with various degrees of completeness, and involved various forms of geologic development.

An early, middle, and late stage - the last may or may not coincide with a closing stage - is to be distinguished in every major tectonic or magmatic cycle. I developed these ideas in 1940, and published them in a paper in 1944; the fundamental purpose of this paper was the elucidation of the over-all characteristics and laws that underly the structure and development of the tectonic-stratigraphic zonal components of mobile belts /9/.

At that time, of course, D. V. Nalivkin, V. I. Popov, A. V. Peyve, A. P. Markovskiy, O. S. Vialov and S. S. Schultz had already treated similar problems for Central Asia. V. A. Obruchev, A. B. Arkhangelsky, N. S. Shatskiy, D. V. Nalivkin, M. A. Usov, V. V. Belousov, and other geologists had undertaken studies of these problems for other parts of the USSR, and in part for the USSR as a whole.

Recently, however, Soviet geological literature has been enriched by a number of valuable contributions on the fundamental problems of the periodic laws that govern the development of mobile belts, and the essences of the various aspects of that development. A very incomplete list of the geologists who made these contributions would include V. V. Belousov, N. A. Belyavskiy, Y. A. Bilibin, O. S. Vialov, P. N. Kropotkin, M. V. Muratov, A. V. Peyve, V. M. Sinitsin, N. M. Strakhov,

[1] Translated from Izvestiya Akademii Nauk SSSR, Seriya Geologicheskaya 1953, no. 2.

e. V. Khayn, N. P. Kheraskov, and
. A. Shtreys, and S. S. Schultz.

My field studies of the geology and magatic relationships of Central Asia, and arious synthetic treatises, journal artiles, and monographs on other areas, contitute the canvas upon which the analysis eveloped in this paper is set out. Varius aspects of the geology of mobile belts - pecifically the time and space laws that overn the development of structures and nagmatic processes - find an especially raphic expression in Central Asia, where he late Precambrian, early middle and pper Paleozoic, and Mesozoic geosynlines are arranged in a north-to-south uccession in the northern Tien Shan. 43.0 N, 80.0 E)

These features deserve special attention n the Pamir region of Central Asia, (38.0 73.5 E) inasmuch as one can evaluate the ntire contribution of Type I interior geaniclines - similar to those observed in the 'ien Shan ranges - to the tectonic-stratiraphic evolution of the region during Paleozoic and Mesozoic times. This type f geanticline has not received sufficient ttention from Soviet geologists, for a numer of reasons, and the elucidation of their ctual structure and tectonic development s obscured by geologists' concern with the nterior geanticlines of an entirely differnt kind and origin /1, 5, 14/. The latter re Type II interior geanticlines, into which the geosynclinal deposits are folded uring the middle and late stages of geoynclinal development.

The displacement of the geosyncline of Central Asia, from north to south, with the assage of geologic time, is superimposed n a more general "double" movement of he crust, which has been recognized by eologists for a long time. This is the ecessary "compensation" of every geosynlinal flexure in the crust by the uplift of n adjacent geanticline. This is why it is ossible to observe very readily, in Cenral Asia, the extent to which, and the inensity with which, the older, more northrly, structures and stratigraphic seuences are involved in crustal movements, agmatic activity, and sedimentation in he younger, more southerly, belts.

Specifically, the orogeny in the southern belts gave rise to "shallow" and "deep" zeugogeosynclines - i. e., to structural basins in which all thicknesses of younger sediments, from "negligible to "great" were deposited. The stratigraphic sequences in the "deep" zeugogeosynclines can be distinguished from cratonic sequences by a number of characteristics, and the crustal movement in these older belts is such that there is no warrant for including them in cratonic regions. Further, there is no warrant for treating zeugogeosynclinal sediments as either cratonic or "geosynclinal" in the strictly extra-cratonic sense /1, 10/. All of the unique characteristics of the Neogene-Quaternary stage of the Alpide cycle find sharp expression in Central Asia. As far as I am concerned, the geologic evidence entirely justifies the inference that this stage represents a radically new phase of an entirely irreversible process, and that this is typical of every mobile belt in the crust.

There is no doubt that a total irreversibility also marks crustal movements in older geologic epochs. The demonstration of this principle, of course, requires great coordinated effort by Soviet geologists, and a great deal of work in the analysis and generalization of a huge body of data, which has been accumulated in all branches of geology. N. M. Strakhov /13/ has made a successful beginning in the study of sedimentation from this standpoint. In addition, one can find publications (some definitely controversial) in the older and newer Russian geological literature, in which profound and pervasive changes in the course of iterative geological processes are identified and elucidated - i. e., in which the over-all structural and lithological configurations of two successive stages, in a regional geologic evolution, will be entirely different.

The irreversible nature of the tectonic, magmatic, and metamorphic processes that occurred in early Precambrian time is recognized generally. We might note, in addition, that the concept of the "cycle" did not prevent geologists, in Central Asia, Kazakhstan, and other regions from addressing themselves to the fundamental differences among different magmatic cycles, the relationship between the structure of each cyclical process and the over-all

regional geologic configuration, and the specific nature of the transitions from one cycle to another /10/. The igneous complexes, in these regions, have not been studied in sufficient detail, and the phrase "in general" occurs more frequently than any other phrase in the publications of these geologists. In addition, there is, in these publications, an entirely arbitrary and robot-like division of igneous complexes into "orogenic" (geosynclinal) and "cratonic" (platform).

Some attention is directed, in the present paper, to the treatment of various questions connected with the nature and terminology of geosynclines and the tectonic-stratigraphic complexes that characterize the early, middle, and late stages of mobile belt evolution. In the course of our remarks on this subject, we also make several points with respect to the specifications of regional magmatic activity and metamorphism. I hope to develop this last theme in greater detail on the basis of the field evidence gathered in Central Asia, in another paper. This treatment will also involve an analysis of the vein mineralization processes that characterize each stage.

TYPE I INTERIOR AND PERIPHERAL GEANTICLINAL UPLIFTS

The mobile belts of the crust are characterized, first of all, by great amplitudes of oscillation, and a great variety of oscillatory and folding movements. The concept of the mobile belts includes the geanticline, with its dominant uplifting movement, as well as the geosyncline with its dominant subsiding movement. Let us consider, first the "interior uplifts" which characterize the first period in the development of a mobile belt, and which are elongated along the trend of the belt; these uplifts can stretch for tens or hundreds of kilometers.

The interior uplift is a fundamental component of the mobile belt at any stage of its development. Any geosynclinal theory that ignores this class of structures necessarily becomes one-sided, and an elucidation of the development of geosynclines, with any considerable degree of accuracy, becomes impossible. The interior uplift - no less than the geosyncline - is a necessary connecting link between one stage in the development of a mobile belt and another.

The distinguishing characteristics of these uplifts is the fact that the rocks which were laid down in the geosyncline which occupied the area during the preceding stage of development constitute their (igneous, sedimentary, and metamorphic) lithology. Further, an interior uplift can exist for a long time within the framework of a younger orogeny without any significant modification of its internal folded structure. It exists, of course, as a great geanticline in its entirety, and as individual areas of uplift and strong erosion in its parts.

One should not imagine that the interior uplift is a homogeneous area of continuous tectonic elevation and erosion, which feeds detritus to the surrounding geosynclines. These geanticlines also include depressions of various sizes and shapes within their limits; as one expects, however, the sedimentary thicknesses, within these depressions, are much less than in the surrounding geosynclines. It is important to bear in mind, however, that these sedimentary thicknesses are not necessarily negligible.

I apply the term Type I geanticline to such interior uplifts. The word "interior" fixes their position entirely within the mobile belt, and presupposes the presence of analogous Type I uplifts along the margins of the belt, at its boundary with the craton. The geanticlines at the margins of the belt are Type I peripheral geanticlines. M. V. Muratov's Carpathian-Stavropol geanticlinal zone (48.0 N, 28.0 E), and the Variscan - and partly Alpide - mobile belt north of the Black Sea, are examples of this type /6/. The entire Tien Shan system, and a considerable portion of that part of Central Asia which lies within the Alpide mobile zone, can be treated as a Type I peripheral geanticlinal zone; we shall point out presently, however, that the geologic history of Central Asia, during Neogene and Quaternary time, introduces a number of fundamental amplifications into the concept.

The Type I geanticline, at the margin of a geosyncline, has been the object of

udy by American geologists for a long me, and has received the name "border nd." The current clearly one-sided and echanical approach to geosynclinal the-ry characterizes these lands as areas of owerful, prolonged uplift, which are rongly eroded, and which supply the ad-cent geosyncline with detritus, especial- during the early and middle periods of eosynclinal development.

The movement of the border land hanges its character, and involves sub-idence and burial under the detritus pro-uced during the next tectonic stage, only fter the folding has terminated, and only the entire geosynclinal zone has been plifted.

The example of interior uplifts, in the ariscan mobile belt of Western Europe he Czech Platform, the Schwarzwald, e Vosges Mountains, the French Central lassif), and in the Alpide mobile belt of orth America (the Colorado Plateau and e Great Basin) is sufficiently clear; hese instances are described in detail lsewhere /7/. A great interior geanti-line developed in Central Asia and Kaz-khstan in Variscan times. It extended rom the Ulu-Tau (54.20 N, 56.50 E) to the orthern Tien Shan, and included the luyun-Kum (43.7 N, 72.0 E), a consider-ble portion of the Golodnaya Steppe 40.6 N, 68.4 E), and the western portion f Central Kazakhstan, as well as the nor-hern Tien Shan. To the south, in the Tien han-Pamir region, the interior uplifts of e Variscan mobile belt were located be-ween Darvaza (40.2 N, 58.4 E) and the issar (39.0 N, 68.0 E) range (V. I. Po-ov's Karategin uplifts), as well as in the egion of the so-called crystalline series the southwestern Pamir, and in the Ta-im Basin (39.5 N, 83.0 E) between the ien Shan and the Kun-Lun (29.50 N, 15.50 E) ranges. The Macedonia-Rhodope 41.40 N, 24.35 E) geanticline can serve as n example of the interior uplift in the ariscan mobile zone north of the Black ea /6/. The Marmarosh zone, in the rans-Carpathian area (Ruthenia), and the liskhano-Zangezur (40 N, 46 E) zone in the rans-Caucasus are examples of analogous tructures in the Alpide mobile belts. hese and a number of other examples, hich I will not indicate here, characterize ese interior uplifts with a sufficient definiteness as great geanticlinal units within mobile belts; their lithologies are dominated by ancient - Precambrian and Caledonian - metamorphic and igneous rocks.

The presence of occasional anticlinal basins, quite deep and filled with considerable thicknesses of sediment in some cases, are characteristic of the middle and late periods in the development of mobile belts; although in the majority of cases, these geosynclines are quite shallow. Occasionally they are connected to the very extensive geosynclinal basins on the craton. The sediments laid down in such basins - especially if a nearly cratonic set of structural relations is carried over into the next period of the belt's development - can almost entirely cover the ancient interior uplift and thus attenuate their contribution to the subsequent geologic history of the belt. The Muyun-Kum (44.4 N, 72 E), Kyzyl-Kum (44.0 N, 64.0 E) and the Tarim Basin (39.5 N, 83.0 E) are istances of this type of development. Apparently, however, quite another structural characteristic is encountered in the Alps and Carpathians: in these regions, geanticlinal basins and their ancient crystalline basements are involved in folding and thrusting, in the early stages of their development, to such an extent that the structure of the belt becomes exceptionally complex. This is to be seen in the interior sections of the western Carpathians, in the Dolomite Alps, and in the Pennine ranges.

There is no doubt, in the case of the Marmarosh zone of the Soviet Trans-Carpathian area (Ruthenia) (48.28 N, 23.2 E), that the lower Mesozoic - its thickness does not exceed a few hundred meters - and the ancient crystalline basement upon which it rests, were involved in Alpide folding; this area, beyond any doubt, is an interior uplift. It is entirely possible that there are areas, in the Alpide mobile belt, in which all of the movements occurred by thrusting. A series of such relationships in the Mesozoic of the west Marmarosh zeugogeosyncline has been studied by V. I. Slavin, and was demonstrated in the course of the 1952 field trip of the L-vov Geological Society.

We do not encounter such relationships in Central Asia. The Caledonian and Variscan complexes, in the northern Tien

Shan, are entirely different in point of structure and degree of metamorphism, from the Precambrian basement on which the Mesozoic deposits rest. The interior folds and metamorphic effects in the latter are entirely Precambrian. Apparently there is no instance, in the relationship between the Precambrian gneisses and crystalline slates, on the one hand, and the lower and upper Paleozoic sediments, on the other hand, that is similar, in the western Pamirs. Thus, the intensity of the tectonic movements, in the interior portions of mobile belts (Type I geanticlines and geosynclines alike) complicates the mapping of the initial, simpler, structures; one must bear in mind, however, that such complicated thrust zones exist side by side with areas in which the tectonic and stratigraphic regime is cratonic or nearly cratonic. Naturally, the contribution of the Type I geanticlinal area to the tectonic and stratigraphic evolution of a mobile belt is also masked to a very considerable degree.

Type II interior uplifts - i. e., geanticlines of small and middle size which constitute areas of outcrop of ancient basement among the geosynclinal sediments of a given stage of development - seem to affect the evolution of the belt over a much shorter period, and are buried under contemporary sediments at a relatively early time; the outcrops of Caledonian and earlier systems in the Chatkal-Naryn (41.40 N, 71 E) zone of the Tien Shan, which are covered transgressively by Devonian and lower Carboniferous sediments, are an example of this Type II geanticline. Eroded nuclei of anticlinoria or fault blocks bounded by faults on all sides are encountered quite frequently on Type II geanticlines; these outcrops are entirely a consequence of recent erosion. In these cases, however, the tectonics are either what they were at the time of the last orogeny, or a more recent movement is postulated arbitrarily - i. e., the paleogeographic interpretation is frequently entirely wrong.

TYPE II GEOSYNCLINES, AND TECTONIC-STRATIGRAPHIC CONFIGURATIONS FOR EARLY AND MIDDLE STAGES OF MOBILE BELT DEVELOPMENT. TYPE II GEANTICLINES.

Geosynclinal basins, or more simply, the geosynclines within a mobile belt, are treated here as great tectonic-stratigraphic complexes within the largest Type I geanticlinal uplifts, or between Type I interior and peripheral geanticlines. In some cases, this frame of reference will resemble the traditional framework of geosynclinal theory very closely. More specifically, such geosynclines will resemble the Appalachian or Urals geosynclines; in some cases, the depressions will be smaller.

The interior and peripheral components of a Type I geosyncline are to be distinguished on the basis of size as well as on the basis of their position with respect to Type I interior uplifts. The tectonic-stratigraphic complexes (for which other authors use the term formations) are represented, in these interior areas, by "green" siliceous, and argillaceous-phyllitic shales, limestones, and graywackes. Volcanic deposits are frequently quite thick, and indicate long periods of continuous submarine volcanic activity. Petrographically, the volcanics are dominated by the spillites and keratophyres; great intrusions of basic or ultra-basic igneous rocks occur simultaneously with the volcanic outpourings, or a little later. The relationships of this igneous complex to the tectonics and stratigraphy of the immediately preceding stage of geosynclinal development are not always clear, and are frequently treated as stratigraphic or tectonic conformities. In some cases, the older sequences are clearly cratonic:[2] in others, there was evidence of a continued interior geosyncline environment over a long period of time. Such, for example, are the relationships in the lower Paleozoic - the Cambrian and Ordovician - in the interior geosyncline of the Alay-Kokshaal (40 N, 74 E) in the Tien Shan Variscan mobile belts.

[2] We cannot accept the conclusion drawn by V. M. Sinitsin, N. M. Sinitsin, and A.V. Peyve that the Lower Paleozoic in this area is cratonic /12/. The figures which they present for the formation thicknesses for the Lower Paleozoic in this area are are very arbitrary, and were taken crosssections that are not complete, and in which the tectonics are extremely complicated.

The transition from the early to the iddle stage of geosynical development characterized by tectonic movement-pecifically, uplift and folding in the axial rea of the geosyncline. This movement, course, can convert considerable porons of the geosyncline into an uplift - pecifically into a Type II, or an "axial iterior" - geanticline. Unlike the Type I plift, however, it is the sediments laid own during the immediately preceding age of the cycle that constitute the litholgy of this type of uplift. Such, for examle, was the early folding in the middle nd upper Devonian in the Alay-Kokshaal. he lithology of these folds is determined y Silurian and lower Devonian sediments nd lavas. The spread of the geosynclinal nvironment over the entire mobile belt oincides, more or less, with the existence the Type II interior geanticline - as if e development of this geanticline comensates for the development of the geosynline. Indeed, the thick, uniform sediients of the upper and middle Devonian, nd the entire lower Carboniferous, are naracteristic of the Chatkal-Naryn zone the Tien Shan, and indicate a peripheral eosynclinal environment there. That is say these sediments were laid down in e outer geosynclinal area at precisely e time that the axial Alay-Kokshaal geancline developed to the south.

These events were accompanied by local ansgressions (manifested as unconformies) in the outer areas of the mobile belt; iese sediments were deposited unconformbly on Precambrian and Caledonian strucures, in the same manner as in the areas djacent to the interior uplift. These anient structures constitute the basement of ie system that are subjected to the action f the Devonian and Carboniferous tectonic nd depositional forces. Outcrops of the ncient basement, at the crests of comparively small geanticlines, and on the exosed surfaces of fault blocks, are comion enough near the outer margins of a eosyncline. These outcrops are quite are in the interior areas, where they ppear only as outcrops of Precambrian rystalline basements in areas in which ock faulting has occurred (the Atbashi ange and the Uch-Chat (41.3 N, 76 E) assif in the Alay-Kokshaal) (40 N, 74 E). eripheral geosynclines with this type position and history can be termed marginal basins (Ye. D. Karpov). The proviso that these basins be distinguished sharply from autogeosynclines near the margin of the craton, of course, is to be observed rigorously if we are to adopt this definition.

The case in which we can identify the interior and peripheral components of a mobile belt on the basis of the tectonic and igneous-petrographic standards which we have developed above is far from frequent, even in those large geosynclines in which the diagnostic features have been dominant from the very beginning of their development.

The tectonics and stratigraphy of the marginal portions of a mobile belt, and the geosynclines with which we are concerned exhibit a great variety of characteristics but, nevertheless, they possess a set of fundamental features which permit their grouping into a single, though rather elaborate category of tectonic-stratigraphic complexes. A. V. Peyve and V. M. Sinitsin divided these diagnostic features into two categories: "primary" and "secondary" geosynclines /10/. V. V. Belousov groups these characteristics into one division of the unjustifiably broad "parageosyncline" category /1,2/. These diagnostic characteristics constitute a part of V. Khain's /15/ distinction between "incomplete" and "inherited" structures. It is important to note that the structures in the outer portions of the mobile belt are associated with the early or middle (here predominantly the middle) stages of mobile belt evolution. One should keep in mind, in addition, that the following fundamental features override the entire complexity and variety of geologic conditions (local unconformities and disconformities, variations in thickness, change in facies, etc.).

1. The sediments laid down in such geosynclines are separated from the older basement by a sharp break, or by a set of more local stratigraphic breaks, in which case there are areas in which the deposits lie conformably upon older but similar facies. There are instances in which these last are clearly identifiable as cratonic /10/.

2. "Subsequent" Type II geosynclines (see below) form on the sedimentary and igneous rocks deposited during a given

stage of development in some areas.

3. The degree of metamorphism in any given formation is inevitably negligible. The only significant metamorphism is the compaction of clays and silts to argillaceous shales and siltstones, or only into argillaceous shales; the lavas and tuffs are never transformed to green shales.

4. The igneous formations and series - very thick in some areas - are dominated by neutral and (in part) acid rocks (andesites, dacites, liparites). The basic igneous rocks, including the spillites, are either subordinate or entirely absent.

5. The folding in the outer geosynclines is substantially less complex than in the inner; second-order folds and minor thrusts are absent, and domes are infrequent.

Great variation in lithology and facies is also characteristic of these areas. The pelitic and igneous rocks are supplemented by (frequently thick) limestones and mineralogically heterogeneous sandstones and conglomerates. Thinly layered series that indicate a regularly rhythmic environment of deposition, in shale-sandstone-limestone flysch or flysch-like basins are to be found side by side with monotonously uniform sandstone, shale, limestone, and igneous formations. The lower Paleozoic - Cambrian and Ordovician - deposits of the Talass Ala-Tau (42 N, 72 E), the Kirgiz range, the Golodnaya Steppe, and the western margins of Central Kazakhstan are examples of geosynclines in the "outer" portion of a mobile belt. The Cambrian and Ordovician sediments in the Kara-Tau and in the western portions of the Talass Ala-Tau underlie an analogous outer geosyncline of mid-Paleozoic age; the stratigraphic break here comes in the upper Silurian formations and, in some areas, there is no angular unconformity. The mid-Paleozoic deposits are sandstones of mid-Devonian and possibly early Devonian age, and are succeeded by thick limestones of upper Devonian and lower Carboniferous age; this geosynclinal zone is charaterized by exceptional lithologic uniformity, and extends far to the east (it is, in fact, the Chatkal-Naryn (41.40 N, 71 E) geosynclinal zone). This geosynclinal series is supplemented by a quite varied geosynclinal series of the same character and Silurian-Devonian-lower Carboniferous age in Central Kazakhstan.

The Verkhoyansk-Kolyma Mesozoic complex is analogous to the Permo-Mesozoic complex in the southern and southeastern Pamirs, and the Permo-Triassic complex in the Trans-Alay, and illustrates the differences in size and nature of geosynclines that belong to the outer portions of mobile belts.

I cannot agree with A. V. Peyve and V. M. Sinitsin when they combine, under the head of "secondary geosynclines," structural basins that make their appearance in the early and middle stages (e.g., the upper Paleozoic of the Urals and the Tien Shan), and include, in this same category, the characteristic lower and middle Carboniferous geosyncline of the northern Tien Shan /7,8/. Again, the category, "primary geosynclinal system," considered as a depression or "furrow" that is adjacent to an area of cratonic outcrops, is extremely arbitrary and, quite obviously, can not be applied to the upper Proterozoic and mid-Paleozoic of the Tien Shan. In addition, the inclusion of Kober's outer flysch in this category is without foundation, and not entirely clear; such basins occupy a different position, come into being at a different developmental stage, and stand in an entirely different relationship, to the "metamorphides" than the so-called first-order geosynclinal system /10/.

Let us return to the problem of the tectonic relationships in the Type I (i.e., the largest) geosynclines. It will be noted here that this type of basin must be taken as being subject to conversion into an "intrageanticline" by means of a "partial inversion, if we apply Belousov's concepts of the "intrageosyncline" to the Type I basin. The widely used terms "intrageanticline" and "intrageosyncline" are inadequate inasmuch as no specification of their position in the mobile belt, or the stage at which they develop, attaches to the terms. This is especially true when these terms are applied to the largest mobile belt structures inasmuch as the arbitrary, relative meaning of each term permits its application to either a depression or an uplift. To be sure, the the variety of tectonic conditions, within any large structure, justifies a very detailed componential analysis of the structure

d the application of special terms to the maller) components, and to the components of the total sedimentary sequence d down in the basin. "Negative components" and "positive components," can rve as such terms; they can refer to ructures that have emerged over the dution of an entire developmental stage, or me shorter period. Of course, such an alysis of the tectonic history, and an idenication of the stratigraphic units that corspond to the various stages of that hisry, can lead to an identification of even ier components. The "anticlinal shoals" "welt basins" postulated by N. M. Sinitn (1948), or M. V. Gzovskiy's "elementry zones" /5/, are examples of such haller units.

We shall conclude this section by condering, very briefly, the metamorphic enomena that characterize the interior osynclines.

The problems of the characteristic ade of metamorphism for interior geonclines, the problems of the developmenl stage at which this grade of metamorism appears, and the distribution of metorphic facies over an interior geosynine are quite complex; any adequate dission of this problem, necessarily, ould be beyond the scope of the present per. We will merely limit ourselves to e remark that the zones of high-grade etamorphism - the zones of crystalline ates, gneisses, magmatite, and gneissic anite - are to be found in the interior, ntral portions of geosynclines[3]; these e the "central complexes." I do not are Peyve's and Sinitsin's view that these ystalline slates and granitic and gneissic nes are Precambrian in age in the Alps, the Variscides of the Pennine Belt, or the Saxonian-Thüringian area (Kober's etamorphides"); this school of thought s yet to demonstrate its position /10/. e school of geologists, for example, rerds the Variscan granites and gneisses as ancient rocks that were involved in, and recrystallized by, the Alpide orogeny; another school, however, regards these rocks as entirely Alpide. This last view was demonstrated quite conclusively for the Variscan "windows" in the eastern Alps - the Tauern section, for example - where the Variscan complex, presumably, was produced by the movement of a Mesozoic shale cover over a granite "putty" /7/.

Regional metamorphism, in interior geosynclines that are quite typical otherwise, will not involve the presence of phyllites and green slates in every case, or even in the majority of cases, as would be required by an excessively schematic application of the diagnostic criteria for such a region; the Alay-Kokshaal, in the southern Tien Shan, is an example of this. One need only point to the fact that the Silurian in this area is represented by graptolite shales, and not by phyllites, and that the grade of metamorphism, in these shales, is lower than in the sediments laid down in some synclines of late Paleozoic age. This circumstance, incidentally, was the source of numerous stratigraphic and tectonic errors and "discoveries" in the Alay and Fergana (40.3 N, 71.5 E) region. This is the characterizing feature of the Alay-Kokshaal (approx. 40 N, 74 E) geosyncline. The folding and low-grade metamorphism of the Paleozoic rocks in this area are largely, if not entirely, of late Paleozoic date. The structures that occupied this region at the end of Devonian time consisted of a broad Type II geanticline, and a group of Type II geosynclines; all these structures belonged to the late stage of the mobile belt cycle.

We have seen in the Alps and the Carpathians, however, that other structural relationships are to be found in interior geosynclines. In the Alps, for example, the Eocene flysch developed transgressively across a Variscan complex that was involved in downwarping some time before late Cretaceous time, while the interior portion of the Variscan zone of Western Europe (Saxony-Thüringia) was the scene of metamorphism before the deposition of Carboniferous sediment began. Apparently, the more typical Type I geosynclines are characterized by just such features. Such geosynclinal belts are to be distinguished from the type of geosynclinal belts which

hese crystalline complexes are central only with respect to the larger uplifts - the larger domes and brachyanticlines. Ring dikes and the igneous stocks with which they are associated are another type of structure altogether.

we encounter in the southern Tien Shan. The latter type of geosyncline, apparently, is characteristic of the outer portions of the mobile belt; geosynclinal conditions are somewhat less strongly expressed there.

This set of standards permits us to go on to a classification of Type II geosynclines that belong to the early stage of mobile belt development, with respect to the stage at which they underwent maximum development, maximum folding and regional metamorphism, and igneous intrusion. The application of this set of criteria permits the classification of Type II geosynclines into two categories: Alpine and Tien Shan.

INTERIOR AND OUTER GEOSYNCLINES IN THE LATE STAGE OF MOBILE BELT DEVELOPMENT

A Type II interior geanticline forms in the inner portion of the mobile belt during the middle stage of development, and sometimes during the transition from the early to the middle stage. This geosyncline is consequent upon folding, intrusion, and uplift in the outer portions of the belt. The folding and uplift, however, do not involve the several interior and outer geosynclines in their entirety; sedimentation continues without interruption in various portions of the Type II geosynclines, through the late stage. The majority of the geosynclines that characterize the late stage in the development of a mobile belt, however, witness a more or less significant break in sedimentation; the sedimentation in this stage, incidentally, covers the eroded folds that came into being during the previous stage, and these include outcrops of the large, granitic intrusions associated with the end of the middle stage.

The development of subordinate downwarps in Type I geosynclines in which the interior uplifts have not been eroded, and which, therefore, can be classed as outer geosynclines, follows the same course. The end of the middle stage, in these portions of mobile belts, is marked by a radical intensification of uplift, folding, intrusion, and the generation of Type II anticlines; some of these anticlines are included in older uplifts, or in Type I geanticlines. The late stage of development is marked by the fact that Type II geosynclines form, through more or less continuous histories, on all of the structures in the belt. Both "inherited" and superimposed" geosynclines are present at this stage.

Late Variscan (largely upper Carboniferous and partly Permian) basins and formations that belong to the late stage of mobile belt development are abundant in the Tien Shan ranges. I refer the reader to the Kurama complex in the southwestern Tien Shan, which has been studied in considerable detail by N. P. Vasil'kovskiy. This basin developed on a mid-Paleozoic basement in the Chatkal-Naryn marginal zone. The rocks are predominantly volcanic, and are divided into a number of series by breaks and unconformities. A considerable number of granitic intrusions cut the volcanics. These latter are dominated by acid (dacitic and liparitic) rocks; a considerable basic (andesitic) component is also present.

A number of contemporaneous geosynclines, of the same date as the Kurama complex, have been studied recently by N. M. Sinitsin, V. M. Ognev and other geologists, in other sections of the Tien Shan Variscan belt, and mainly in the interior geosynclinal portion of the belt. Volcanic rocks are virtually absent in this area, and shales, sandstones, and conglomerates constitute the lithology; typical flysch deposits make up at least part of the regional sequence.

Foredeep deposits are typical of the late stage of mobile belt development; the Urals, Carpathian, and North Caucasian foredeeps can be taken as entirely illustrative examples of these structures, which constitute the connecting element betwwen geosyncline and craton. The interior regions of the foredeep (these, of course, adjoin the folded regions in a mobile belt) share the predominantly geosynclinal attributes of that belt; the marginal regions, on the other hand, share the attributes of cratonic basins of deposition. The foredeep, then, can be treated as a Type I marginal geosyncline that has undergone great subsidence in the late stage of mobile belt development.

The late stage of the Variscan develop-

ment, in the southern Pamirs /7/ deserves especial attention. The upper Paleozoic (the Permian) is entirely continuous with the early Mesozoic (Rhaetic-Liassic); this structural depression continued to exist, in Mesozoic time, as a Type I Kimmeridgian geosyncline in which the Variscan marginal uplift was gradually obliterated. It is interesting, also, that the Triassic and Jurassic structures in the Alps conform to the structures in the underlying Permian formations.

The structures that mark the late stage of mobile belt development, in the northern Tien Shan (these are middle and upper Carboniferous and possible Permian), conform intimately with the structures in the lower Carboniferous, and possibly with some structures in the upper Devonian. The basement upon which they rest is made up of the crystalline rocks of the core of the Tien Shan Type I interior geanticline; they are separated from this basement by a great regional unconformity. These deposits are represented, in the foothills of the northeastern Kara-Tau (43 N, 70 E) and in the western Kirgiz Range, by a relatively thin (1000 to 1500 meters) series of red beds that consist, in the main, of arkose and argillaceous shales, with subordinate lower Carboniferous limestones and gypseous layers. The attitude of the limestones and gypseous layers is horizontal or gently monoclinal. Extremely complicated structures are encountered, however, at the boundary with the crystalline basement in narrow zones along the margins of the ranges. These complexes resemble very similar Tertiary complexes, for which they were mistaken formerly. One might also add the observation that the structure of the Carboniferous formations, in the vicinity of the town of Dzhambul (44.4 N, 73.1 E), is much simpler than the structure of the Tertiary formations in the adjacent foothills of the Talass Ala-Tau /7, 8/.

The Dzheskazgan (46.55 N, 66.4 E) geosyncline in Kazakhstan, and the nearly undisturbed middle and upper Carboniferous sediments that fill it, have many features in common with the upper portion of the cross-section of the basin in the northeastern Kara-Tau and the western portion of the Kirgiz Range; the sediments that fill this latter basin are mildly deformed and, in some localities, nearly horizontal red and brown arkoses and argillaceous shales of lower and middle Carboniferous age. Contemporaneous and possibly younger (Permian) formations attain considerably greater thicknesses in the eastern portions of the Kirgiz Range, in the Trans-Ili Ala-Tau and in the Ketmen (43.3 N, 81 E) Range; these sequences include a number of volcanic members, and predominantly acid igneous complexes. In addition, these complexes have undergone complicated deformation which has led to the development of mountain ranges. In some cases these structures are associated intimately with the more ancient structures of the northern Tien Shan; many granitic and syenitic intrusions are also present.

The entire ensemble of characteristics for these complexes resembles the complex in the Variscan geosyncline of the southern Tien Shan (the Kurama geosyncline, for example) and is to be distinguished quite sharply from the complexes in the Dzhezkazgan basin and the Dzhambul district. Thus we find, in the "interior regions" of the Variscan mobile belt in the northern Tien Shan, geosynclines which are characteristic of the late stages (and to some degree the middle stages) of mobile belt development, with regard to formation thicknesses and lithology. The sequences of sediments in these geosynclines resemble the sequences in cratonic geosynclines. There is no doubt that late geosynclinal sedimentary sequences pass gradually into cratonic sequences, and that the distinction between the two is arbitrary to some degree. The late geosynclinal sequence, however, possesses an entirely characteristic set of properties, and is readily identifiable in the majority of cases.

The appearance of interior and marginal geosynclines, as well as their burial in the late stages of mobile belt development, is a characteristic corollary of the development of a great Type I geanticline. The appearance of the geosynclines is associated with local uplifts, of a secondary magnitude, which are superimposed upon the great Type I uplift. The sedimentational environment for certain segments of the stratigraphic column resembles the environment in the "tectonically neutral" cratonic basins.

The over-all history of the Tien Shan

during the Alpide orogeny is that of a Type I marginal geanticline. This orogeny was characterized by a number of interesting tectonic features: the depth and shape of the geosynclinal depressions into which the Paleozoic and Precambrian basement was deformed in order to receive the Jurassic coal-bearing series (the Kara-Tau, the Fergana range, the Angren (41.05 N, 70.1 E) district, etc.), or the Cretaceous and Paleogene sediments of the Alay, Gissar (39 N, 68 E), and Fergana ranges, the Tashkent Chuli, the Tadzhik ranges, the southwestern Kara-Tau foothills, etc.

The sediments in many of these basins are quite different from the typically cratonic Cretaceous and Paleogene sediments of the Golodnaya Steppe (north of the Kara-Tau), the Kyzyl-Kum (40 N, 65 E), and the Kara-Kum, especially with regards to the thickness of the sediments and the complexity of the folding. One need only point to the fact that the thickness of the virtually horizontal Cretaceous and Paleogene sediments in the Golodnaya Steppe is some tens of meters, while the thickness in the Tashkent Chuli is more than a kilometer. There can be no doubt, however, that the cratonic sediment of the Golodnaya Steppe area would be found to grade into the much thicker geosynclinal sediments of the Tien Shan if they were traced from the one area into the other. This, in spite of the fact that the thickness of the Mesozoic and Cenozoic sediments attains five or six kilometers in some sections of the Trans-Alay and the Tadzhik ranges. Similar examples of early and late Mesozoic geosynclines, developed in the interior and marginal portions of a Type I geanticline, are also to be found in other areas. We will limit ourselves to indicating that the relatively thin Mesozoic and Cenozoic series, along the northwestern margins of the Marmarosh geanticline in the Trans-Carpathian area, were deposited in such basins. Much thicker and much later (Miocene) deposits were laid down in these same basins subsequently /4/.

Data published by V. Ye. Khain /16/ indicate that a thin series of sediments was laid down, in upper Cretaceous and Eocene time, over the Miskhano-Zangezur Type I geanticline in the Trans-Caucasus; a deep geosyncline, the Yerevan (41.1 N, 44.3 E)-Ordubad (38.55 N, 46.06 E) depression, at the southern margin of the geanticline, received the sediments during Paleocene and Miocene times, however. A marginal geosyncline came into being along the northern margin of the Miskhano-Zangezur uplift in late Cretaceous times; this was the Sevan (40.3 N, 45 E)-Kurdistan geosyncline.

We can summarize the fundamental characteristics which, taken together, constitute a set of criteria for distinguishing between late-stage geosynclines and cratonic (structural) basins:

1. The thickness of the sediments, typically, is of the order if several kilometers in the mobile belt geosyncline, and of the order of several hundred meters in the cratonic geosyncline.

2. The folding in the mobile belt geosyncline is intensive and involves the entire geosyncline. On the other hand, fold- is confined to the margins of the cratonic geosyncline, and so this structure is characterized by great undisturbed or gently domed areas.

3. Very considerable thicknesses of igneous rock - dominated by the neutral or acidic species - are characteristic of the geosynclinal deposits in the (late) stage with which we are concerned; one should add that these igneous rocks include small granitic intrusions. There are areas, however, in which an abundance of neutral or acid volcanics and small granitic intrusions are associated with relatively undisturbed geosynclinal sediments; this is consequent upon the tectonic position of the geosyncline (proximity to a present-day ocean basin, for example). Such, for example, are certain Cretaceous-Paleogene geosynclines near the eastern margins of the USSR, and certain areas in the western United States, where Tertiary geosynclines were the scenes of intensive volcanic activity. There are such areas, also, in England and Scotland. Interestingly enough, the deeper and more intensely deformed Mesozoic and Cenozoic geosynclines are extremely poor in igneous rocks; specifically, acid volcanics and granties are entirely absent. This is true of the Jurassic of the Fergana range and the Kara-Tau, the Cretaceous and the Tertiary of the Tashkent Chuli, the great Neogene basin in the Naryn geosyncline, and many other areas.

V. V. Belousov applies the term "parageosyncline" to geosynclinal and geanticlinal depressions associated with the late stage of mobile belt development; V. M. Sinitsin, A. V. Peyve, and Ye. V. Khayn, on the other hand, refer such basins to a residual geosyncline category /2, 10/. I have already pointed out that the concept of the parageosyncline is extremely broad and indefinite, and that the concept of the residual geosyncline, as broad structural depressions that resemble cratonic geosynclines, is valid only for certain late Variscan basins in Kazakhstan and the northern Tien Shan. The upper geosynclines of the southern Tien Shan do not have such characteristics; these characteristics are lacking, also, in the deep Jurassic geosyncline of the Fergana Range area and the Kara-Tau, and the differences are especially marked in the case of the Neogene-Quaternary geosyncline that occupied the entire Tien Shan region. None of these areas can be regarded as "great, level areas surrounded by gentle uplifts... that constitute zones of attenuated erosion" /10/. The concepts and terms pertaining to Type II late-stage geosynclines, and structural basins that come into being in the middle and late stages of mobile belt development, in the interior and marginal regions of Type I geosynclines, are much more specific. They satisfy a matured need for a specified and documented set of terms to counteract the excessively broad, ambiguous concepts that document tectonics today. They also satisfy a need for a more firm and precise frame of reference within which to develop the analysis of the evolution of mobile belts.

The boundaries between Type I and Type II structures are frequently tectonic - thrusts or faults that may extend for tens or hundreds of kilometers. Such, for example, is the Tien Shan trunk fault, mapped by V. A. Nikolayev between 1930 and 1933. This fault can be traced for one thousand kilometers; it separates the ancient Tien Shan complex (i.e., the Variscan interior anticline) from the Variscan geosynclinal complex of the southern Tien Shan (the marginal Kara-Tau and Chatkal-Naryn zone).

A thrust zone separates the Mesozoic complex, in the central Pamirs, from the lower and mid-Paleozoic geosynclinal complex in the northern Pamirs. In 1936 I diagnosed this thrust zone as a structure that has the same kind of first-order significance as the Tien Shan trunk fault. N. A. Belyavskiy subsequently traced this thrust zone eastward into the Kun-Lun and Karakorum (36 N, 76 E) ranges, and showed that the thrust zone, in the Pamirs, was a western continuation of the Uprang thrust zone, which separates the Mesozoic geosynclinal complex of the Karakorum from the Paleozoic geosynclinal complex of the Kun-Lun /3/.

As early as the 1930's, V. I. Popov classified the Tien Shan trunk fault as a so-called "discordogenic" fault that can remain more or less active over a span of time that includes several geologic periods, and which separates a zone of uplift from a zone of subsidence and sedimentation /12/. At the same time, or a little later, S. S. Schultz, V. N. Ognev, and N. M. Sinitsin expressed similar views. It was not so long ago that A. V. Peyve developed a concept of deep faulting which has much in common with the analysis elaborated by Popov /9/. Peyve, who categorically denied the existence of the Tien Shan trunk fault as late as 1939, called this the Torsk-Kara-Tau deep fault.

I regard the fundamental characteristic of such deep faults as open to question, and not demonstrable by ordinary geologic methods. Their prolonged existence cannot be demonstrated if the paleogeographic analysis of the surrounding region is incomplete. The asymmetrical shape of basins and uplifts, the existence of relatively steep structural "slopes," regional faults with varying dips and positions - all of these factors give a much sounder explanation of rapid changes in geosynclinal facies. In addition, a major fault - this is especially true of the Tien Shan trunk fault - appears later than folding, thrust faulting, and igneous intrusion at the boundary between a geosyncline and a geanticline.

The appearance of granitic dikes or elongated stocks or batholiths is associated directly with such great faults, or with areas in which the termini of shorter faults approach each other. There are excellent examples of this in the Tien Shan and Pamir ranges. The granitic intrusions move along the weakened zones between different struc-

tures, or between formations laid down at different times, and, so to speak, unify different facies into a single complex. The variation in the lithology and structure of formations, in plan and cross-section, in general, and especially in structures at the margins of mobile belts, the sharp breaks at boundaries of more ancient folded and intruded complexes, the relatively shallow depth at which the ancient complexes are buried under more recent, highly variable formations, which, in turn, include stratigraphic breaks - all of this creates conditions that are favorable to the appearance of faults, block tectonics, and intrusive and extrusive igneous rocks. This would offer a partial - though far from complete - explanation of the strict delineation of the major granitic intrusives in the Tien Shan; these igneous rocks intrude into a highly variegated sequence of sediments. The homogeneous major sedimentary deposits in the area, on the other hand, are virtually devoid of igneous intrusions.

In a word, the granitic intrusion occurs in the late stage of mobile belt development, and at the end of the middle stage in some cases.

THE CLOSING STAGE OF MOBILE BELT DEVELOPMENT. THE UNIQUE NATURE OF LATE ALPIDE TECTONICS.

A. V. Peyve and V. N. Sinitsin draw the inference, from the rest of their view of the problem of inherited geosynclinal structures, that it is entirely wrong to postulate the existence of great uplifts with dissected relief up to the very end of a given geosynclinal regime. More specifically, they hold that the completion of folding and deposition coincides with a leveling of the topography and the appearance of a peneplane. They base their line of argument on N. M. Sinitsin, who stated, as early as 1947, that "The example of the Tien Shan shows that ... the Hercynian folding concluded in Permian times, with peneplanation, and not the appearance of new mountain systems." /10/

If we treat these most interesting and original conclusions as an approach to a true generalization for the closing stage in the development of a mobile belt, our very next experience is the discovery that the generalization is entirely inapplicable to the closing stages of Alpide folding. To be sure, entirely cratonic conditions can be discerned in the Tien Shan ranges for the Paleogene and the initial stages of the Neogene; the relief is level, and one encounters sequences of red beds in cratonic basins which are entirely analogous to the mildly deformed or entirely horizontal red beds of Permian age (described by N. M. Sinitsin), or the late Variscan red and variegated sandstones and shales in the northern Tien Shan and central Kazakhstan (the northeastern Kara-Tau, the west Kirgiz foothills, the Dzhezkazgan basin, etc.).

However, there was an exceptionally strong renewal of orogenic activity in the entire Tien Shan system, in the Pamirs, and in a considerable portion of Central Asia, in Neogene and early Quaternary time. High, intensely dissected mountain systems came into being, together with deep interior and marginal geosynclines; these latter were filled with thick, predominantly coarse, molasse deposits. These deposits, in turn, were folded - intensely in some areas - by thrusting, folding, and faulting in the uplifts that surrounded them. It should be noted that the mountain masses which applied the stresses to the sediments in the geosyncline were made up of consolidated sediments that were laid down during the Variscan and earlier cycles.

We see, at once, a direct contradiction to - not merely a departure from - Peyve's and Sinitsin's analysis of the closing stage of mobile belt development, and any other suggestion that this stage might be represented by a cratonic peneplane.

This is why the most recent - late Alpide - orogeny, in Central Asia, cannot be fitted into Peyve's and Sinitsin's scheme, even if we assume that the Alpide cycle of uplift and sedimentation has not come to an end yet.

The suggestion that this region is a deformed foreland of the Alpide geosyncline (Kober), that it is a belt of plications confined to the sedimentary veneer (Argand), or that it is a rejuvenated geanticline or geosyncline (V. A. Obruchev), deserves a certain amount of attention. This last suggestion is very closely related to Kober's concept of the "neopalides";

Obruchev's interpretation, however, requires specification, inasmuch as we are dealing here with a deformation which (a) occurred in the recent past, and (b) was confined to a marginal portion of the Alpide mobile belt. Further, the movement was anticlinal in its over-all aspect; the exceptionally sharp outlines of the uplift, and the exceptional intensity of the forces released within it, created a very complex and varied mountain system. The configuration of the intermontane basins, of course, is also complicated, and the deposits (of Neogene and Quaternary age) laid down in these basins possess a set of completely characteristic features.

This combination of tectonic movements, sedimentation, and intense geomorphological dissection is characteristic of the closing stage of mobile belt development in other Alpide mountain systems which include interior geanticlines separated by geosynclines in which Mesozoic and Cenozoic sediments have been laid down. The Siwalik zone in the Himalaya foothills and the Ganges basins in the southern portions of the Alpide mobile belt are examples of this.

It is also difficult to agree that the documentation of the conclusion that even geosynclinal regions older than Alpide are completely filled with sediment and peneplaned - as Sinitsin and Peyve maintain - is complete. This conclusion should not be dismissed entirely, however; it can serve to emphasize the unique nature of the late Alpide orogeny, in Asia and in the northern Type I geosynclines of the Alpide belt, to the extent that it is valid.

One can hardly find, in all of geologic history, a movement with as great an amplitude, intensity, and areal extent - a movement that involved equally great areas of craton and consolidated sediment - as the Alpide orogeny. There is every reason for treating the late stage of the Alpide crustal movement as the beginning of a new stage in the development of the mobile belts of the Earth. This movement is increasing the width of these mobile belts, in spite of the fact that the individual Mesozoic and Cenozoic geosynclines are being narrowed.

This crustal movement is superimposed upon the clearly irreversible tectonic history of the Tien Shan, and adjacent areas of Central Asia. It can be demonstrated that the late Alpide renewal of tectonic activity has affected every major structure and every formation in this area, beginning with the Precambrian. This can be seen in any cross-section for the area.

The entire analysis can be summarized by means of the following key:

1. Interior geosynclinal complexes.
2. and 3. Complexes at the margins of mobile belts.
3. and 4. Complexes in cratonic structural depressions.

An application of this key to Central Asia gives the following results:

A. Northern Tien Shan:
- Precambrian - 1
- Caledonian - 2
- Variscan - 3

B. Chatkal-Naryn zone:
- Precambrian - 1
- Caledonian - 2
- Post-Variscan - 3
- Alpide - 4

C. Alay-Kokshaal:
- Variscan (involves early Paleozoic structures) - 1
- Late Variscan - 2
- Alpide - 3

It is only natural that all districts will not be characterized by a superposition of three or four structures. The number of structures in which a given district is involved depends, of course, upon the areal extent of the structures of each stage of development.

The closing stage of mobile belt cycles older than the Alpide can be discerned, for example, in the latest Variscan "residual red basins," or in analogous basins in the northern Tien Shan and central Kazakhstan. The closing stage, however, is also represented by the Permian lavas of the Kyzyl-Naryn (Kurama zone), the Permian liparites, tuffs, and volcanic breccias of the southern Gissar, and possible the contemporaneous and lithologically similar volcanics in the upper portion of the cross-section for the Trans-Ili Ala-Tau, the

Ketmen, and the eastern portion of the Kirgiz Range. All of these volcanics are cut by dikes and stocks of granite porphyry, aleskite, syenite, syenite-porphyry, and diabase.

It was pointed out, long ago, that there seems to be no relation between the exceptionally weak (comparatively) late volcanism, and the intensity of the late orogenic movements, in the Tien Shan, the Pamirs, and adjacent areas in Central Asia. This feature of the tectonic history of the Tien Shan was ascribed to the fact that the history consisted of folding and overthrusting and, in general, was specified by the action of compressive stresses rather than the horst-and-graben structures to which block faulting gives rise in other portions of the Alpide mobile belt. Volcanic activity, on a major scale, will occur in block-faulted areas in which the displacement is much less than it is in Central Asia. What is involved, fundamentally, is the presence of faults - i.e., channels - along which the magma can move.

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THE PROBLEM OF UNDERSTANDING THE NOMENCLATURE OF FACIES [1]

by

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• translated by Eugene Alexandroff • [2]

Two points of view exist among geologists concerning the problem of definition of geological conceptions and ideas. One part of the geologic profession thinks that it is more convenient to use the most widespread and generally accepted terms such as "geosyncline", "facies", "formation", "stratum". "layer", and other, as widely used terms, without making an attempt to put them into the Procrustes' bed of precise terminology.

The other point of view is contrary to the first. It is based on the circumstances that many misunderstandings and obscurities in modern geology are the result of wordiness of definitions, inaccuracy of terminology and nomenclature, and of insufficiently clear delimitations of terms. The writer supports entirely the opinion of the linquist Schuhardt quoted by N. B. Vassoevich /5, p. 32/, who said that a terminological obscurity in science is the same as fog in navigation. This obscurity is dangerous because it is not realized by the people involved. A regulation of terminological problems would result in the reduction of unnecessary controversies in cases where an agreement could be achieved, or where a precise boundary between different concepts could be drawn.

The author supports the last point of view. Modern geology, with its subdivision into a series of subjects, needs, first of all, clear and precise definitions. Lack of clear definitions hinders mutual understanding and utilization of the knowledge of one geological science division by other divisions. It makes difficult the creation of general theories as well as their fruitful practical application.

In the present paper the author is trying, and not for the first time, to make a more accurate definition of such an important geological term as facies /6/.

Recently, N. S. Shatskiy expressed himself definitely in respect to "facies" in contrast to "formation". N. S. Shatskiy is entirely right in protesting against the existing confusion in geological literature of the meaning of the words facies and formation.

"The term formation is very frequently and incorrectly confused with facies", says N. S. Shatskiy, "facies has a more general meaning than formation. In fact, the term formation is first of all a tectonic and general geological conception, since the formation is always related to definite tectonic forms, and definite geological structures" /16, p. 9/. It is impossible to talk about molasse and flysh facies, since molasse consists of deposits of different genesis. The expressions "coal-bearing" or "petroliferous facies" should not be used, if one means coal-bearing and petroliferous formations, and not facies.

Making, however, an approach to the definitions of the concepts of facies and formations, N. S. Shatskiy excludes facies from the sequence of concepts of sedimentary rocks. He distinguishes among the latter the following: "Three groups of mineral formations: (1) rocks, (2) genetic and lithological-genetic deposits or complexes (for example, continental deposits, pro-

[1] K VOPROSU O PONIMANII I NOMENKLATURE FATSIY, translated from Izvestiya Akademii Nauk SSSR, Seriya Geologicheskaya, Feb. 1847, no. 2, pp. 7-14.

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luvial deposits of the piedmonts - among the continental deposits, and different, still badly-differentiated marine genetic types of deposits, (3) formations which represent a natural complex groups of rocks and deposits of different genetic types, but which are united by the common tectonic conditions under which they formed" /16, p. 12/.

Discussing the concept of facies, N. S. Shatskiy refers to the author of this conception, to Gressly, and comes to a conclusion, that "according to the old interpretation of the subject, in the 30's and 40's of the last century, the substance of the stratum, lithological series, stage and stratigraphical series is reflected by its age and position in the stratigraphical column; while the facies (sandy, marly, and others) is only the external appearance of the stratum, an indication used by the paleontologists and stratigraphers of the last century. However, this indicates at times a sharply changing external feature, the facies. But this indication is not essential, because it does not interfere with the essence of stratigraphic layer, which means it does not interfere with its age".

At the present time N. S. Shatskiy is of an opinion close to that which we mentioned above. He says, "from the point of view of a geologist, facies of any concrete sedimentary formation belonging to the groups mentioned above, is represented by another rock of the same age, and more frequently by a contiguous rock, another genetical complex, another formation, which is always stratigraphically related to the same stratum series, system, etc." /16, p. 12/.

"The study of concrete facies may therefore be conducted only in stratigraphical aspect, as facies, lithological, and paleontological changes of a definite stratigraphic unit; study of the formation may be also conducted independently from any stratigraphical limits" /16, p. 12/.

If we make an analysis of these definitions and illustrate their separate elements with examples, then these definitions will have the following aspect:

1. Facies is a relative concept pertaining to the distinctions which always correspond to one stratigraphic unit (e.g. facies to red sandstones, carbonaceous facies of Middle Devonian), although this unit may differ in magnitude from other units.

2. Facies as external appearance or feature relates to the distinction of one deposit from another deposit of the same age according to their lithological and paleontological, but not genetical, characters.

The meaning which is incorporated in the conception of facies is naturally reflected, first of all, in the appropriate terminology. Therefore, proceeding from the foregoing, N. S. Shatskiy avoids such facial definitions as abyssal, alluvial, lagoonal, etc., because they include the genetical and paleogeographical features, and not the lithological and paleontological ones.

However, N. S. Shatskiy indicates that in connection with the progress of historical geology, and especially that of paleogeography, at the end of the 19th century and during the first quarter of the 20th century, "facies have been considered as conditions of sedimentation, or as a combination of lithological and paleontological features of deposits, indicating in a broad sense the physiogeographical environment of this deposition" (continental, deltaic, pelagic, etc.). "This interpretation of facies should be termed paleogeographical".

Without making an objection to such an interpretation of the facies as proposed by A. D. Arkhangelsky and D. V. Nalivkin, N. S. Shatskiy absolutely rejects the consideration of facies independently from the stratigraphic position as genetical deposits in general, because, according to his opinion, such an interpretation of facies "substitutes without any reason the important conception of the genetical types of deposits and conditions of their deposition which has acquired general recognition after the publication of the classical works by A. P. Paylov dedicated to the continental Quaternary deposits. In this sense, - continues N. S. Shatskiy, T. A. Davydova and Ts. L. Gol'shtein are right in describing similar mineral formations as genetical and lithological-genetical complexes of deposits, as well as Yu. A. Zhemchuzhnikov, N. M. Strakhov, V. S. Yablokov, and others, who speak of exactly the same for-

mations as facies in the same sense /16, p. 11/.

To our regret, N. S. Shatskiy, discussing the paleogeographical interpretation of facies, has not more accurately defined the correct application of this term. He presents, as an example of paleogeographical facies, such facies as "continental", "marine", etc. In our opinion these are certainly not facies but very broad groups of facies, "conditions of deposition", whole geomorphs consisting of an intricate association of facies of different origin.

From another point of view, the vertical alterations in cross section are apparently not considered by N. S. Shatskiy to be the result of facies changes because they represent deposits superimposed upon each other, are in general not of the same age, and cannot belong to the same stratigraphical unit.

Such an interpretation of facies represents a reversion back to Gressly from the new ideas of A. D. Arkhangelsky, A. A. Borisyak (the latter has been forgotten by N. S. Shatskiy) D. V. Nalivkin, and the majority of other modern scientists. This interpretation hardly relieves the difficulties connected with discrimination of facies and differentiation of this term from the rocks from one side, and geological formations from the other. It is easier to distinguish these three categories (facies, rock and formation) through the introduction to the definition of genetical principle. Actually, facies of a deposit is distinguished from the rock by the fact that the latter is determined lithologically (e.g., sandstone, limestone, clay, etc.), independently from the genesis. Sandstone or sand may be of fluvial, glacial, eolian, or marine origin, which determines, according to our opinion, the facies of the proper deposits, corresponding to either rock, and not to the facies of rocks.

Facies is easily distinguished from formation due to the difference in magnitude of both conceptions. Almost all formations consist of different facies. Namely, of different rocks which are of different genesis. A format is a complex of facies. N. S. Shatskiy is protesting against the confusion of terms, facies and formation. But the quotation: "Facies alteration of Lower Visean deposits becomes obvious in the substitution of the coal-bearing formation of the West by the petroliferous formation to the East in the European part of the Union" (see further), probably does not contradict the interpretation made by Shatskiy. In this case the facies has a very broad meaning which is equal to a whole series or to a a formation, which is composed of multiple facies, according to our interpretation. According to N. S. Shatskiy this may be a series, a complex of rocks, and even a whole formation (the latter is hard to understand: how can a whole formation be a facies? As such a broad (and indefinite) conception, the term "facies", becomes the scientific synonym of such words as "distinction", "modification", "variety", "peculiarity". N. S. Shatskiy, however, despite such a wide application of this term, limits it to the lithological and paleontological composition, rejecting the genetic distinction which is not included in his definition. Why? For what reason? Solely, as one may think, because of the priority of the definition by Gressly /17/. But Gressly introduced the conception of facies at a time when the genetic approach paleogeography, geochemistry, paleoecology, and other sciences, did not exist or were in an embryonic stage of development. Attempts at reversal back to the initial meaning of purely stratigraphic notions of the middle of the last century are obviously doomed.

Speaking about the "genetic" types of rocks, which have been described by A. P. Pavlov /12/ 68 years ago, N. S. Shatskiy wants to attach to Pavlov's words a terminological meaning. But A. P. Pavlov wanted only to demonstrate the diversity of continental deposits according to their origin. His purpose was not to subdivide the marine deposits according to types. He did not offer any general terminology based on the genetic principle. N. S. Shatskiy proposed to apply the term formation to paragenetic complexes of rocks. Rock, as a combination of many features such as composition, structure, texture, etc., is also a brief term. Shatskiy does not assign such a special brief term to the genetic units. The majority of geologists, and lithologists in particular, apply the term facies to those sediments which are delimited in detail according to their

origin. This does not at all eliminate the priority of Pavlov and does not reduce the importance of his work.

A. D. Arkhangelsky /1/ introduced a new and substantial contribution to the facies study. Using the so-called comparative paleogeographical method, he gegan to treat the conception of facies from the genetic, paleogeographic, or paleogeomorphological point of view.

The great importance of the "facies methods", stressed by A. D. Arkangelsky (discovered by A. I. Andrusov) has been especially emphasized and formulated by A. A. Borisyak. The latter highly appreciated the monograph by A. D. Arkhangelsky /1/, and thought that in respect of this method the monograph created an epoch in the development of historical geology, due to introduction of comparative facial analysis as basis of stratigraphic studies.

A. A. Borisyak understood the term facies as the reconstruction of conditions formation of sediments and existence of fauna which dominated during the accumulation of sediments. In connection with this concept, A. A. Borisyak also considered paleogeography to be a science dealing with the reconstruction of geography of the past geological periods and epochs /8/.

A. A. Borisyak /3/ wrote about facies in connection with the new problems of historical geology: "Besides the stratigraphic sequence, which certainly maintains the value of a general groundwork or guide in the work of a geologist, facies analysis of the studied sedimentary series should be the first step. In this interpretation some kind of limestone, mottled sandstone, cupriferous and other shales, will help to reconstruct the active water basins or continent, where the sediments have been deposited, and serve as material for the formation of rocks mentioned above".

In another place /4/, A. A. Borisyak speaks about the problems of historical geology: " A layer in the earth's crust represents (to historical geology - Yu. Zhemchuzhnikov) not only the rock studied by a petrographer, but a sediment deposited in a certain basin which (the basin) becomes the final object of study. In the same way the organic remains in this layer are of interest to historical geology, not as representatives of a definite stage of evolution of a given group of animals, as they are considered by the paleontologist, but as remains of fauna of the studied basin, related to that particular region of the bottom where the given deposit has been formed. Or on the contrary, peculiar to the whole basin, or even to many basins, and therefore allowing the establishment of the simultaneousness and the correlation of all different sediments (beds) of a given geological moment".

Further on A. A. Borisyak explains: "in other words, the same specimen of rock is studied by the petrographer from the point of view of its composition, and by the paleontologist who examines the fossils and draws the phylogenetic conclusions. Meanwhile the historical geologist considers this specimen as a fossil facies, one of many facies of the studied basin (or dry land), and looks into its lithological and paleontological features only for collecting information necessary to reconstruct this facies. From the point of view of historical geology, any layer of the earth's crust represents a definite facies, and therefore facies study is one of its cornerstones.

In an almost similar way the conception of facies has been understood by the group of Moscow geologists (M. Kozakov, G. Mirchink, N. Strakhov, E. Shantser,) who criticized the newly published handbooks of historical geology. They wrote: "Historical geology is interested in facies not as in rock and fauna, but as in a document illustrating the physiogeographical environment under which this rock and fauna have been deposited. It is just this environment which historical geology is aiming to interpret."

Finally, it is necessary to take into account, with respect to methodology, the important book, by N. M. Strakhov, Problems and Methods of Historical Geology, 1932 /15/.

It results without any doubt from the content of this work that the whole complex of the basic problems of historical geology consists, in fact, in reconstructing

different physiogeographical and bionomical conditions. Following A. D. Arkhangelsky, N. M. Strakhov interprets facies as the reconstruction of formerly existing conditions.

After reading the books by A. D. Arkhangelsky /1/, A. A. Borisyak /3,4/, A. N. Rozanov /13/, it is impossible not to be able to distinguish the genetic feature of the facies. This is the same as if somebody, after having solved a problem, fails to consider the import of its solution. This cannot happen, as the primitive definitions and conceptions of the early 19th century cannot be continuously accepted.

The task of facies study, and analysis of facies, consists of the reconstruction of sedimentary facies according to the genetic features of the rock or the features of the primary sediment. If we accept the point of view of N. S. Shatskiy, that is, if we see the differences in facies in all features of the rocks (not only in the genetical features), then we should speak about the facies of bituminous coal and anthracite facies. Meanwhile, in all these cases we have to do only with peat facies. The diagenetic and metamorphic features have nothing to do with the facies. The sands may go over in an area into sandstones, silts into argillites, calcareous silts into limestones and marbles. Not every lithological and even paleontological dissimilarity represent facies distinctions. But all genetic peculiarities (for example, fluvial and coastal marine sands) represent facies dissimilarities.

The understanding of a facies in the sense of petrographical or paleontological peculiarities of deposits of the same age, allows a geologist to limit himself to the elementary empirical definition of facies. For example, the Devonian calcareous facies may be contrasted against the facies of red sandstones, facies of Kazanian stage containing Brachiopoda - against the Permian Pelecypoda-bearing facies of the same age. This kind of understanding of the conception results from the poor definition once made by Gressly.

It is shown persuasively in a thorough paper by N. V. Vassoevich /5/ that Gressly was not consistent in his discussion of facies and terminology, and attached to them distinctions with emphasis on the conditions of sedimentation. The predecessors and the contemporaries of Gressly understood these distinctions in a similar way before the term facies had been introduced.

N. S. Shatskiy supports the formal definition made by Gressly 120 years ago.

American geologists subdivided this conception of facies into conceptions of lithofacies and biofacies. It is probable that the geochemical facies should also be included, as distinctions established 100 years later (due to the progress of the science), but also according to one group of features.

What is the substance of the primary Gresslian (19th century) and modern (20th century) definitions of facies? The point of the matter is in the fact that the first concept is empirical, and the second is genetical. The whole development of the geological science during the last century represents a progress from the empirical notion to the genetical, which reveals the origin and history of the facies.

If the problem of facies were settled in the discrimination between the calcareous and the clayey and sandy rocks or in the ability to distinguish Brachiopoda from Pelecypoda, no special "facies study" would be necessary to solve this small problem. The "facies study" begins there where the problem of reconstructing the environment and the conditions of the past emerges.

If one supports such a conception, it is necessary to reject the possibility and necessity of the general facies study.

As we see, there is another important distinction between the concept of facies we are analyzing and that which we consider as only contemporaneous. The first is only an immediate (visual) statement, and the second - a notion about the environment, the elements and the general picture of which still has to be restored by means of certain methods, science, and scientific concept. In other words, the knowledge of facies is not given directly but is deduced and is reconstructed in quite other terms than those which are used in the

description of rock. The rock possesses structure, texture, composition, etc., but the facies - the environment - is not characterized by these qualities, it is characterized by the depth of the sea, distance to the shore or by the current of the river, glacial or desertic accumulations, i.e., generally speaking, by the geomorphy, in the broad meaning of the word.

It is proper to stress a third distinction in the interpretation of facies: the interpretation by N. S. Shatskiy is purely stratigraphical, while that proposed by the author is paleogeographical.

If one takes in consideration the second interpretation of the facies as reconstruction of the ancient geomorphy, as the restoration of all conditions of the medium of deposition which determine the accumulation of sediments and life or organisms. If we are logical, a series of necessary conclusions will follow this interpretation.

In the sense of terminology, we cannot talk about a sandy or calcareous facies, because the sandy deposits may form under marine, coastal, fluvial, deltaic, lagoonal, desertic, glacial, and other environments, i.e. they may be of different genesis. Therefore, sandy facies are heterogeneous, and saying "sandy facies" means nothing.

In a similar way the term "Pelecypoda facies" does not explain anything, because Pelecypoda may be marine, brackish water and fresh water dwellers. In other words, the group of "Pelecypoda facies" is heterogeneous in the same manner as the group of sandy facies, and does not indicate any definite conditions of sedimentation.

As we are standing on the basis of genetic conceptions and genetic terminology, it is important that instead of the name of rock, the definition of the sediment should be taken in consideration: not limestone - but calcareous silt, not coal - but peat, peat bog where it accumulates, facies of a peat bog - this is what has to be considered.

Therefore, if one is consistent, facies of some kind of secondary rocks (e.g. secondary quartzites) cannot be taken into account, because they do not represent different conditions of sedimentation, but a heterogeneity in further transformation of sediments. Besides that the concept of facies is inapplicable to the metamorphic rocks (e.g. marble facies, gneiss facies). Again, one cannot use the expressions "lignite facies" "anthracite facies", etc., because lignite and anthracite could be of the same genesis and could form in the same facies of the primary peat bog. However, further geological events transformed peat in this case to the rank of lignite, in another - to the rank of anthracite. Gressly and other founders of the conception of facies have born in mind, nevertheless, this sense of distinction in the primary deposition of the rock.

Finally, such polygenetic series, as the coal-bearing, petroliferous, and other series, which are now unified within the formations, cannot be called coal-bearing, petroliferous, or some kind of other facies. We are dealing here with paragenetic complexes of many and, at times, rather varied facies. And even within the boundaries of coal-bearing formations, as had been shown in my earlier paper, a series of distinctions may be established in respect to assemblage, range, and other peculiarities. Consequently, we are dealing here with a whole group of formations.

In conclusion it is necessary to make a statement, that in the definition of the sense of a geological facies a duality which was emphasized several years ago by N. B. Vassoevich /5/, existed and exists until the present time. The origin of the duality is in the inaccuracy of the definition made by A. Gressly. A result of the "original sin" as it has been called by N. B. Vassoevich.

But since the completion of the work by Gressly (1837-1841) science has advanced and new trends in geology have developed. The facies approach, which is more and more dominant in Russian and Soviet geology, has transformed many of its branches. Some subjects, for example lithology, petrology, and others, have outgrown the stage of empirical description and entered the field of genetic correlation and interpretation. This development became contradictory with the old concepts and definitions which remained empirical

(descriptive).

The question arises, what should be done? To simplify, to degrade the new content of the geological sciences in order to gratify the priority of primitive definitions, or to put modern sense into the old concepts? We are backing this second way of more accurately defining scientific terminology; the way which was used in defining other basic geological concepts (geosyncline, and others). It is necessary, therefore, to give a new definition of facies which is a result of the whole development of the Soviet and world geology.

At the present time the term facies is interpreted by the majority of interested geologists[3] as the environment of sedimentation and ecology of organisms. This has to be established in the new and more precise definition. This definition has to be genetic (paleogeographical), restorative, sufficiently limited to narrow boundaries, and explicit.

We are proposing a new, more developed definition than that given by us in 1948 /6/ but showing the same trend.

Facies reflects the environment of the accumulation of sediments and the formation of a certain layer (bed, horizon). This environment is reconstructed on the basis of the lithological characteristics, paleontological content, geochemical features and other evidence.

If it is impossible to completely reconstruct an environment according to the present level of knowledge, we may at least expose the conditions of sedimentation and ecology by means of an analysis of separate features of the rock and fossils. Then in our definition, the word "environment" may be substituted by the word "conditions", but the substance of the facies analysis will not change. This will be a conclusion drawn from the rock to the original sediment, from the primary features of the sediment to the conditions under which it has formed, and to the life of organisms in a suitable medium.

Finally, if this sandy deposit can produce no evidence as to its genesis, we are not entitled to term this deposit as facies, because we don't know the facies of this sandstone. In other words we don't know whether this sandstone is marine, fluvial, eolian, or some other kind. If we refer to it as "sandy facies", we will start a fruitless tautology. It would be more correct to say simply: "sandy deposit, or rock".

It is understood, that besides our definition, several more or less extended versions may be proposed, but their genetic substance will remain the same. From our point of view definitions are inadmissible which begin as follows: "facies is a rock, etc." or "facies is a layer of rock, etc.".

It is obvious that facies is not a rock and not a layer, not the petrographic composition, and not the paleontological content of a concrete deposit in which we are interested.

Facies is that which may be conceived or deduced from all indicated material features of a rock and layer to come to a conclusion about the sediment and the physiogeographical, biochemical, and geochemical conditions of its origin.

Is it possible in our time to use the empirical and visual interpretation of facies besides the genetic understanding of facies for contrasting the differences of one stratigraphic horizon, as it is done by N. S. Shatskiy, without making an attempt to take a look into the problem of genesis?

This is possible, but the conservation of such definitions cannot be tolerated, as the ancient relics in many domains of science cannot be tolerated. Namely, those relics which are inevitably forced out by new ideas due to the development of facies analysis, lithology, paleobiology, paleogeography, and other subjects. It is only our ignorance, inadequacy of methods and results in facies study of today which may serve as an excuse for the coexistence of such definitions.

[3] I am speaking of interested geologists, especially about lithologists, because the tectonicists, for instance V. V. Belousov or A. V. Ronov, operate with elementary "facies", more correctly, with groups of facies (sandy, clayey, calcareous, coaly) and are not interested in their genesis.

But what is going to happen tomorrow? Tomorrow, due to progress of knowledge of modern and buried fossil facies, only an "idea" about the facies may remain. It may concern different facies, replacing each other in the same layer (horizon), or facies superimposed upon each other in the sequence, or finally, considered separately from each other. This idea will include not the material features of the rock (which represent only the records) but the characteristics of the medium of formation of the sediment and life of the corresponding fauna and flora.

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THE PRESENT STATUS OF THE THEORY on the ORIGIN OF OIL AND TASKS FOR FURTHER INVESTIGATION[1]

by
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INTRODUCTION

In this report are briefly set forth the highlights of the status of the presentday theories on the organic origin of oil, and a short survey is presented of various other hypotheses on oil formation, in particular the inorganic origin of oil.

Differing opinions on specific situations and unsolved questions under discussion are examined. The fundamental tasks for further investigation are outlined under the following major headings:

I. Historical sketch

II. Practical significance of the problem

III. Hypotheses of the inorganic origin of oil

IV. The chief positions in presentday theory on the organic origin of oil

1. Circumstances pointing to the biogenic origin of oil
2. The problem of the original material and the conditions of its accumulation in sediments
3. The means by which organic matter is altered, leading to the formation of oil, and the factors defining the steps and direction of such alteration

V. Differing opinions on specific situations; unsolved questions and questions under discussion

1. Differing views on the question of oil-bearing sediments
2. Differing views on factors determining the transformation of organic matter into oil or gas
3. The most important differing views on the question of the chemistry of oil formation and of the changes in the chemical composition of oil within the earth's crust
4. On the differing views of the question of the primary movement (migration) of hydrocarbons from the original oil-producing sediments into reservoirs

VI. The chief tasks of further research

1. Questions requiring additional study
2. On the factors determining the transformation of organic matter into oil and the balance of energy in the transformation
3. On the problem of recognizing oil-producing formations
4. Questions of the formation of genetic types of oil
5. The study of the geologic laws of the storing of oil and gas deposits

The report was drawn up under the direction of the Orgkomitet for the organization of discussion relating to the problem of the origin of oil.

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The following took part in drawing up the report: Dr. of Geologic and Mineralogical Sciences I. O. Brod, Dr. of Geologic and Mineralogical Sciences V. V. Beber, Candidate in Geologic and Mineralogical Sciences N. A. Yeremenko, Candidate in Geologic and Mineralogical Sciences D. V. Khrabrev, Candidate in Geologic and Mineralogical Sciences S. P. Maksimov, Corresponding Member of the USSR Academy of Sciences M. F. Mirchink, Dr. of Geologic and Mineralogical Sciences A. V. Ulyanov, and Candidate in Geologic and Mineralogical Sciences V. A. Uspenskii.

In drawing up this report wide use was made of a projected report prepared by Corresponding Members of the Academy of Sciences of the USSR M. F. Mirchink, A. A. Trofimuk, K. R. Chepikov, Doctors of Geologic and Mineralogical Sciences A. A. Bakirov, V. V. Beber, M. F. Dvali and Candidate in Geologic and Mineralogical Sciences V. A. Uspenskii. In addition, use was made of materials for the preparation of discussion, drawn up in 1950 by A. A. Bakirov, M. F. Mirchink, S. F. Fedorovich and in 1954 by S. I. Mironov, M. F. Mirchink, S. F. Fedorovich and V. P. Markevich.

The report was adopted by a majority of the members of the Orgkomitet.

HISTORICAL SKETCH

The problem of the origin of oil is one of the most difficult in natural science. Oil does not bear clear traces of the circumstances of its origin; the mobility of oil and gas allows one to assume that their deposits are formed in the process of migration.

All this has created insurmountable difficulties in the solution of this problem. Nevertheless in the nineteenth century many attempts were made to solve it. All contemporary theories of the origin of oil, in fact, have roots in the distant past. Two basic paths were at that time outlined for the solution of the problem: chemical and geologic. On the one had, attempts were made to produce oil in the laboratory by means of chemical experiment, and thereupon to transfer the conditions of the experiment into nature and to place a geologic foundation under the chemical scheme thus elaborated; the majority of such hypotheses, sometimes very circumstantially supported by chemistry, did not withstand criticisms from the geologists. On the other hand, numerous attempts to solve the question were made proceeding from the geologic conditions of the deposition and distribution of oil in the earth's crust, by considering oil as one of the normal representatives of minerals useful as fuel. Such schemes met with insurmountable obstacles in the interpretation of chemical processes.

The peculiarity of all the hypotheses put forth at that time (and, in fact, now as well) was that the authors narrowed their conception of nature down to one which was considered "actually true" but was in reality assumed by them. All the many-sidedness of natural phenomena was excluded (and is very frequently now excluded) from view, along with the possibility that identical or similar materials might originate under varying conditions and by various means.

All the hypotheses on the origin of oil of that time can be classed in two large groups: hypotheses of the organic and those of the inorganic origin of oil.

One of the variants of the inorganic hypothesis of the origin of oil was the hypothesis offered by V. D. Sokolov in 1889. The basis for this hypothesis was the discovery that carbon and hydrogen were joined in cosmic bodies, particularly as methane in the atmosphere of several planets. According to V. D. Sokolov, hydrocarbons were retained in the earth's gaseous envelope during its fiery creation. In the cooling of the earth the hydrocarbons were absorbed by a cooler substratum and, finally, condensed in the uppermost layers in the earth's crust. According to V. D. Sokolov, oil is inherent in many bodies of the universe and its formation must take place by processes that are not random but on a universal scale. This hypothesis never enjoyed the recognition of the learned world and has found supporters only in most recent times (Kropotkin, 1955).

The greatest fame was achieved by the inorganic hypothesis offered by D. I. Mendeleyev in 1877. D. I. Mendeleyev supported his conclusions with a series of

experiments asserting the possibility that oil could originate by inorganic (mineral) means. It remains to be noted that the possibility of oil forming by mineralogic means was already noticed by D. Sokolov (1839) in one of the first courses of earth study in Russia.

Berthelot (1866) in contrast to D. I. Mendeleyev presupposed the existence within the earth's crust of alkaline nuclei; this made his scheme even less acceptable to the geologists.

One variety of the mineralogic hypotheses of the origin of oil is the volcanic hypothesis, worked out in Russia in 1831 by Lenz, and thereafter elaborated by Kost (1905) at the beginning of the Twentieth century.

The inorganic origin hypotheses never enjoyed wide acceptance, and in essence were overthrown at the end of the nineteenth and beginning of the twentieth centuries. In recent times, however, they have again gained currency in the works of MacDermott (1939), N. A. Kudryavtsev (1951, 1952, 1955) and P. N. Kropotkin (1955).

The hypothesis of the organic origin of oil appeared considerably earlier (M. V. Lomonosov). Many facts, both geologic and chemical, suggest the idea that oil is connected with organic matter. Notice was taken of the ubiquitous association of oil with sedimentary deposits of chiefly marine origin.

In the chemical composition of oil are contained the same elements as are in living matter — that is, carbon, hydrogen, nitrogen and sulfur. The difference lies exclusively in the almost complete absence of oil of oxygen, which is characteristic of the organic world. But in coal the role of oxygen, in comparison with the living organic world, is negligible. This circumstance gave one the right to consider possible the formation of fuel minerals (coal and oil) through processes carried on by organic matter.with loss of oxygen. By experimental investigations the possibility was established of obtaining from organic matter (chiefly by means of High-temperature distillation) chemical compounds which in their internal appearance and composition were extraordinarily similar to oil. A little later, finally, it was noticed that certain fatty acids included in the composition of greases and waxes were very suitable as a point of departure for the formation of oil hydrocarbons.

In the second half of the nineteenth century great attention was given the question of the original organic matter. Many different conjectures were made. Some investigators searched for this original organic matter in the plant world, others in the animal, and yet others suggested a mixed plant-animal origin.

Engler's attempts (1888, 1900, 1895, 1907) to turn vegetable and animal fats into oil and, more subtley, into products similar to oil, had a great influence on the development of views at that time on the origin of oil.

Two separate tendencies emerged from the organic theory at the beginning of the twentieth century. The first was a natural outgrowth of the views of Engler-Hefer; it envisioned the accumulation of primary organic matter under special conditions and in great amount. These views were held primarily by chemists. The second was the theory of oil-bearing strata, most clearly set forth at that time in the works of I. I. Andrusov (1906, 1908) and G. P. Mikhailovskii (1906).

There appeared also the idea of hydrogen sulfide contamination of sedimentary basins as a necessary factor in the process of oil formation; this was developed by I. I. Andrusov (1892, 1894, 1908) and by Engler (1900).

According to G. P. Mikhailovich, in the process of deposition of limey and muddy silts on the bottom of the sea, there are deposited along with mineral particles also various animal and plant organisms. The transformation of this buried organic matter takes place in its first stages by means of decomposition due to bacterial activity. In further burial decomposition gives way to a process of bituminization that takes place under growing pressure and temperature.

Potone (1905) developed his views on the mixed plant-animal origin of oil from

silt (sapropelei); his presentation had great influence on the development of ideas on the origin of oil.

Among the factors in the changing of organic matter into oil there emerged, at the end of the nineteenth and beginning of the twentieth centuries, the activities of micro-organisms, temperature, pressure, and even chemical action of the soil. But a clear presentation of the action of these factors was lacking. The possibility that biochemical factors might influence the change of organic matter into oil was mentioned by many foreign investigators, but the study of this factor and attempts to evaluate it were carried out at that time by Russian scientists (Berigaud, 1888; Zelinskii and Brusilovskii, 1885; Nadson, 1903; Andrusov, 1906; etc.)

In the views on the temperature conditions of the formation of oil two notions were fairly clearly built up: that of high- and that of low-temperature conditions. The first idea traces its beginning to M. V. Lomonosov and is clearly influenced by the partisans of the inorganic origin of oil. These views were supported by Engler (1897), Potone (1905), Golier (1915), Adden (1915) and many others. The second tries to regard the process of oil formation as a natural one proceeding in the midst of thick sediments (Mikhailovskii, 1906; Andrusov, 1906; Gubkin, 1916; etc.)

The question of the role of pressure in the oil-forming process was not clear; many investigators noted the influence of this factor without any concrete evaluation of it (Mikhailovskii, 1906; Andrusov, 1906; Engler, 1897; etc.)

In this period great significance in the process of turning organic matter into oil was ascribed also to the chemical action of various soils, chiefly of marine origin (Mikhailovskii, 1906; Andrusov, 1906; Khaveler, 1896; etc.). This idea was pointed to by the chemical composition of the waters accompanying oil, and the observed paragenesis of oil from sulfur and certain soils. The actual interrelationship of oil and the waters traveling with it was clarified somewhat later.

A great role in the organic theory of the origin of oil was played by the thesis expressed by Thompson (1925) and I. M. Gubkin (1932) of the broad regional character of oil formation. They began to consider the process of oil formation as a normal one, going on in the crust of the earth during all the periods of its development, from the Cambrian to the present. The connection between oil strata and sedimentary basins forced one to search for the original formation of oil within the usual conditions of accumulation of sediments. This position furthered the development of the theory of oil-bearing strata. At the same time it began to be possible to regard oil and gas within a single class of fuel minerals (I. M. Gubkin, 1932, 1936), and to consider them as part of the general carbon cycle in nature (V. I. Vernadskii, 1934, 1938).

Subsequently, the consideration of oil within the general carbon cycle has been carried on by many investigators (V. A. Sokolov, 1948, 1951; I. O. Brod and N. A. Yeremenko, 1950, 1957; A. F. Dobryanskii, 1948; V. A. Uspenskii, 1956; etc.)

The study of oil-bearing sediments was begun by Academician A. D. Arkhangel'skii (1927). In 1925 in the Caucasus A. D. Arkhangel'skii discovered a whole series of laws on the distribution of organic matter within rocks. He came to the conclusion that only clay formations can serve as oil producers.

Abroad, an attempt at a detailed study of oil bearing strata and their recognition was undertaken by Trask (1932, 1937, 1939). Trask studied many peculiarities of the organic matter in contemporary rocks and sediments, but could not obtain any trustworthy diagnostic criteria. Recently much attention has been given to the study of such oil-bearing strata. In other countries as here in the USSR, these questions have been taken up not only by individual investigators, but also whole institutes such as VNIGNI, VNIGRI, the Oil Institute of the Academy of Sciences of the USSR, etc.

In this connection can be mentioned the work of V. A. Uspenskii and O. A. Radchenko (1947, 1954), V. V. Beber (1947, 1955), Z. L. Maimin (1955), N. B. Vassoyevich (1955), N. M. Strakhov and K. F. Rodiovova (1955), G. I. Teodorovich (1952, 1954) and many others.

As a result of the study of possible oil-bearing strata the suggestions first made by A. D. Arkhangel'skii were significantly broadened. These oil-bearing deposits to many investigators appear to be an alternation of clayey and thoroughly permeable (sandstone) deposits (V. V. Beber, 1955; Dyakov, 1955; N. M. Strakhov, 1954; etc.)

Along with the study of the accumulation of primary organic matter in its disseminated form, the view regarding its homogeneous accumulation has also undergone development. This view has been most clearly set forth by V. B. Porfirev (1941). According to V. B. Porfirev's presentation the accumulation of primary organic matter takes place in a homogeneous form without any admixture of mineral particles. Similar views were held by A. F. Dobryanskii, though he later abandoned them (1951). This view of the homogeneous accumulation of primary matter has not received wide dissemination among geologists, since such an accumulation of organic matter demands specific conditions which according to geologic concepts are considered unlikely. Later on V. B. Porfirev departed from his extreme views and began to consider as possible the introduction into an original homogeneous mass of a small quantity of mineral particles. As an example of oil-producing strata V. B. Porfirev points to the Jurassic argillaceous shales of the Caucasus. In 1957 V. B. Porfirev again changed his views and adopted the hypothesis of the inorganic origin of oil.

The accumulation of sediments in connection with ocean basins is most widespread in nature. This compels one to connect oil-forming deposits primarily with marine sediments. Factual material amassed in recent years allows one to admit the possibility of oil being formed within subaqueous continental deposits. Such a possibility is indicated by Pen (1941), S. N. Alexeichik (1946), Illing (1946), Van Teil and Parker (1941), Twenhofel and McKelvey (1941), M. F. Mirchink and A. A. Bakirov (1955), M. N. Saidov (1956).

The circumstances of accumulation of original organic matter in thick sediments demanded an exposition of the geochemical environment. The solving of this problem was done in two directions. On the one hand ancient geochemical facies were studied; on the other, recent sediments were studied for the purpose of discovering in them possible conditions for the formation of oil. A tremendous amount of work, accomplished by the study of ancient geochemical facies (by L. A. Gulyayev, 1955; N. M. Strakhov and K. F. Rodionov, 1955; G. I. Teodorovich, 1954; etc.) made it possible to discover the facies most favorable to the formation of oil, and to establish the significance of their pH and Eh. The development of the notion of original organic matter was very essential; and here also a great role was played by the works of N. D. Zelinskii (1941).

As a result of his experimental investigations N. D. Zelinskii can to the conclusion that "...to the chemist falls the task, then, of metamorphosing natural organic materials into petroleum oils; in this connection one may state that, depending on the composition and structure of the natural substances, from their decomposition is formed a mixture of petroleum hydrocarbons in which are contained all the typical hydrocarbons represented in oil, but in a different interrelationship."

There was considerable difference of opinion about the nature of such original matter. Some investigators (G. L. Stadnikov, 1937; K. P. Kalitskii, 1944; V. V. Beber, 1947; A. I. Karasev, 1956; Sh. F. Mekhtiev, 1953; etc.) saw this original material in vegetable matter, often including terrestrial vegetation. In this connection the works of Craig (1953) and Rankama (1956) deserve mention; these find in oil the same interrelationship of C_{12} and C_{13} as is found in terrestrial vegetation. Other investigators assigned a significant role to animal organisms. But the views expressing the mixed (vegetable-animal) character of the original material underwent the greatest development. There was a vigorous discussion of the question: exactly which components of organic matter are the ingredients of oil? The possibility of transforming any component part of organic matter into hydrocarbons was proved in essence, but the relative role played by these parts in the process of oil formation was estimated in various ways.

To this day there is no clear knowledge of the influence of the original matter on the qualitative composition of the oil end-product. Certain investigators consider that the final composition of the oil to a greater or lesser degree depends on the character of the matter from which it originates. (N. D. Zelinskii, 1941; G. L. Stadnikov, 1937; I. M. Gubkin, 1937; V. V. Beber, 1947; I. O. Brod and N. A. Yeremenko, 1950, 1956; Hunt, 1953; etc.)

Other investigators think that there can be no influence of the original matter on the final quality of the oil, owing to either the initial (usrednenya) of the original organic matter (A. F. Dobryanskii, 1948) or else to the influence of the later conditions of its transformation (V. B. Porfirev and I. V. Grinberg, 1949; V. A. Uspenskii and O. A. Radchenko, 1952, 1954).

One must dwell particularly on the question of the presence of hydrocarbons through the agency of live organisms (Krumbein and Caldwell, 1939; Oakwood, 1944, 1945). V. A. Uspenskii and O. A. Radchenko (1954) and Whitmore (1943) assign great importance in the process of oil formation to the accumulation and concentration of hydrocarbons synthesized in the bodies of organisms.

In recent years studies of the conditions of transformation of organic matter within sediments have undergone great development. In the USSR such studies, begun by A. D. Arkhangel'skii in 1925, have been continued by a great number of scientists of VNIGRI and VNIGNI. Without question a large role has been played by the work of N. M. Strakhov (1952, 1954), N. M. Strakhov and K. F. Rodionova (1955) and others. In the USA, among many great investigations in this vein, one must point to the work of Trask (1932), the work of Emery and Shepherd (1945), Murray (1947) and the latest works of Smith (1954, 1956).

As a result of the investigation of contemporary sediments and the processes of transformation of the organic matter within them, by V. V. Beber and A. I. Gorska (1950, 1955) and by Smith (1954, 1956), it has been established that there is an abundance of oil-hydrocarbons within contemporary and Quaternary marine sediments. It has been noted that the quantity of hydrocarbons in bituminous organic matter increases with increase in the depth of its containment. Nevertheless proofs were offered of the generic connection of natural oil with the products of the transformation of organic matter contained in sediments. But, as usually happens, the solution of one problem produced a host of new ones. Chibnel (1934) established that biochemical paraffins have hydrocarbons in their composition, chiefly those with an odd number of carbon atoms. Bray and Kenney (1954), and also Stevens, Bray and Evans (1955), discovered that in the hydrocarbons of oil there are contained about equal numbers of molecules with even and with odd numbers of carbon atoms. At the same time, in hydrocarbons drawn by them from the soil and from marine silts there is a sharp prevalence of hydrocarbons with an odd number of carbon atoms. On this basis Stevens (1956) denies the generic connection between oil and the hydrocarbons of soils and sediments.

Many investigations were carried out with the goal of clarifying the role of the various factors in the process of transforming organic matter into oil.

By the work of many investigators, in particular T. L. Ginsburg-Karagicheva (1927, 1936, 1938, 1940, 1947, 1953, 1954), Zobell (1942, 1947, 1950) and others was shown the leading role of bacterial processes in the decomposition of organic matter under anaerobic conditions in the earlier stages of diagenesis. Finally it was established that bacteria were able to synthesize hydrocarbons within their bodies.

Bacteria exercise an important influence on the geochemical environment in sediments, by bringing about the appearance of lower negative values of the oxidation-reduction potential, that is, creating the means favorable to the processes of bitumen-forming (S. I. Kuznetsov, 1934; Zobell, 1950; etc.) The great role played by bacteria as bio-catalysts has been established. In addition I. M. Gubkin (1937) suggested the possibility of catalytic action by the enzymes of anaerobic bacteria. The investigations of M. A. Massineva (1940) fully supported this idea of I. M. Gubkin's.

Beginning with N. D. Zelinskii's work (1941), the great role played by mineral catalyzers in the process of oil formation began to be evident. Through laboratory experiments by A. V. Frost (1940, 1945, 1946, 1948, 1951) and certain other investigators (P. A. Larin, 1948; A. A. Mekhnevskii, 1942; A. F. Nikolayev, 1943; N. S. Sattarzade, 1954) it was proved that there can be formation of hydrocarbons entering into the composition of oil from organic compounds in the presence of catalytic action by aluminosilicates under high-temperature conditions (150 - 250 degrees). In the USA, A. V. Frost's investigations were continued by Brooks (1952). The latter demonstrated the catalytic action of activited clay minerals without preliminary activization when a certain portion of their natural moisture is retained.

. Brooks (1952) and Bornhauser (1950) associate changes in the properties of all within the earth with the catalytic action of clay, and the latter's catalytic properties with the facies. Hunt (1943), on the other hand, opposes this idea, since in his investigations he did not discover any connection between the catalytic peculiarities of clay and the quality of the oil within strata.

One of the most incontestable factors in the formation of oil is temperature. But the question of the temperature necessary for the process of oil formation has turned out to be one of the most extensively discussed. It turned out that the simplest solution to the problem was to assign a sufficiently high temperature to the transformation of organic matter into oil. Some investigators — V. B. Porfirev and I. V. Grinberg (1948), Roberts (1945) — proceeded along this very path; according to their representations the temperature of transformation must be on the order of 300 - 600 degrees. If the chemistry of the process, according to this scheme, does not call forth any particular objections, nevertheless the geologic environment of the transformation and even the chemical composition of oil call forth very real ones. In considering the process of oil formation as a normal one in thick sediments and widely distributed within them (I. M. Gubkin, 1932; Thompson, 1925), one must also assume a normally widespread environment for such a transformation. The highest temperature noted within the depths of oil-bearing basins only in rare cases much exceeds 100 degrees (140 in Ozeksuat, 168 in Pembin). The capacity of oil-bearing strata varies within wide limits, and thus their submergence at great depths is not very likely; and, consequently, the temperature of oil formation also should not, according to this representation, greatly exceed 100 to 150 degrees.

Treibs (1934) discovered in oil a porphyrin complex, which decomposes easily at temperatures greater than 250 degrees. Nitrogenous compounds decompose at temperatures lower than 250 degrees. V. B. Porfiryev and I. V. Grinberg (1948) suggested the secondary enrichment of oil by porphyrins in the process of their migration. Investigations by O. A. Radchenko and L. S. Sheshina (1955) indicated that, if the enrichment of oil by a vanadium porphrin complex can be considered a secondary process, then the nickel complex of porphyrins evidently is inherited by oil from its organic origin. Danning and Moore (1953) noted that the amount of porphyrins contained in oil is not enough to account for the entire quantity of nickel and vanadium contained in it. A whole series of interesting laws was established in accordance with the nickel and vanadium in different species of oil (O. A. Radchenko and Sheshina, 1955; L. A. Gulyayeva, 1945, 1954; S. M. Katchenkov, 1955; P. Ya. Demenkova, 1954; Sninker, 1952; Hudson, 1954; etc.)

A. V. Frost (1946, 1951) and S. N. Obryadchikov (1946, 1947) suggested determining the temperature of oil formation by the final equilibrium composition of certain hydrocarbons. According to their calculations the temperature intervals within which oil is formed lie between 150 and 300 degrees. S. I. Mironov, G. D. Halpern, Yu. Kolbanovskii (1955) set the lower limit for the formation of oil from 30 degrees (Kara-Bulak) to 45 degrees (surakhanskaya).

PRACTICAL SIGNIFICANCE OF THE PROBLEM

The Sixth Five-Year Plan for the development of the national economy of the USSR foresees that the extraction of oil will be increased almost twice, while the

extraction of gas must be increased to almost four times the level attained in 1955. As N. S. Khrushchev directed in his report to the Jubilee Session of the Supreme Soviet of the USSR, within 15 years the daily production of oil must reach 350 - 400 million tons, and that of gas 270 - 320 billion cubic meters. The accomplishment of these very important tasks demands the increase by every means of reconnaissance and exploration operations for oil and gas. In these operations must be included not only areas that are proven gas and oil bearers, but also widespread territories in the European and Asian parts of the USSR where there has still been no discovery, not only of gas and oil deposits, but even of any signs of oil and gas. The better founded are our suppositions as to the circumstances of oil and gas deposits, the more successful and effective will be the search for deposits of oil and gas.

If the hypothesis of the organic origin of oil is correct, one must search for deposits in zones of great accumulation of the types of sediments among which are contained oil-forming suites. Determining the circumstances of oil-deposit formation makes it possible to discover favorable territories for finding oil deposits.

Adherents of the organic hypothesis of oil formation are divided into supporters of the concept of oil being formed from organic matter concentrated into homogeneous masses, and supporters of the idea that oil is formed from organic material disseminated throughout the sediments of oil-bearing suites. Each of these viewpoints differently evaluates the general prospects of the search for oil. According to the first view oil is formed under exclusive conditions requiring the concentration and retention of large homogeneous masses of organic matter under the conditions of geosynclinal regions. The second viewpoint bases the wide distribution of oil-forming processes upon conditions prevailing in subaqueous basins with sediments in a reducing environment.

The same can be said of the various hypotheses of the inorganic origin of oil. One of these connects the formation of oil with local centers of active appearance of basic magma, limiting the zones of possible formation of oil deposits by the distribution of such centers. According to the second supposition the segregation of hydrocarbons in magma has a regional character and is connected with subcrustal phenomena.

Thus each of the suppositions mentioned demands its own approach and its own criteria in evaluating the possibilities of this or that territory's bearing oil and gas. But only correct representations of the conditions under which oil is formed can furnish a scientific basis for the search for this most important and useful mineral and guarantee the effectiveness of this very expensive geologic search and exploration for oil and gas.

The principles and criteria for evaluating the oil and gas bearing possibilities of this or another territory, proceeding from the above-mentioned suppositions about the origin of oil, are completely in opposition to each other.

An evaluation of the prospects of oil and gas content based on the organic hypothesis of the origin of oil proceeds from a thorough study of the sedimentary mantle of the earth's sphere. Sedimentary rocks of certain defined characteristics are considered by proponents of the organic hypothesis both as the source of oil formation and as receptacles for oil deposits. Supporters of the inorganic-origin hypothesis, on the other hand, consider that sedimentary rocks have no relation to the origin of oil and can serve only to contain oil deposits. Oil, according to this hypothesis, arises in deep magmatic centers which are not amenable to direct study.

When, in the course of searching for oil, any sedimentary rock has been disclosed by exploratory borings, proponents of the organic origin of oil, while not yet finding clear indications of it, on the basis of studying the composition, structure and history of formation of sedimentary rocks with favorable indications for the formation and accumulation of oil, will favorably evaluate the prospects for finding oil in such a territory, while supporters of the inorganic origin, proceeding from their own suppositions, can evaluate negatively the same territory's prospects for finding oil.

In the last fifty years the world's oil industry has had a very rapid growth. The extraction of oil rose from 20,305 thousand tons in 1900 to 835,700 thousand tons in 1956. Such a rate of growth has been obtained by the discovery of more and more new oil and gas deposits. But who has led the practical search for new deposits? Methods of searching for new deposits of oil and gas throughout the world have always been based upon the fundamental positions of the organic theory of the origin of oil, and on the basis of these positions have been discovered the laws and circumstances of the deposition of oil in the earth's crust. This very development of the organic theory of the origin of oil has not only made it possible to discover thousands of new oil and gas deposits, but also to find out and work new oil and gas-bearing regions (provinces).

HYPOTHESES OF THE INORGANIC ORIGIN OF OIL

As has already been noted, in the last decade in the USSR and the USA the expressions of the adherents of the inorganic synthesis of oil have again appeared in print. In the USSR N. A. Kudryavtsev, B. N. Kropotkin and, most recently, V. B. Porfirev have entered upon this path.

Supporters of the inorganic hypothesis direct a series of critical observations at the theory of the organic origin of oil.

They most frequently (N. A. Kudryavtsev) base the very foundation of the inorganic hypotheses upon these critical observations, following the method of proof "by inversion".

The idea of such proofs lies in this, that if the partisans of inorganic synthesis cannot find answers to certain questions in the theory of the organic origin of oil, then the hypothesis of the inorganic origin of oil, which is freed from the necessity of a scientific basis of its own, must therefore be true.

In other cases certain factual data and proofs are brought forth in the service of the inorganic hypotheses.

The circle of proofs on which the proponents of the inorganic synthesis of oil rely is very narrow and, moreover, springs from suppositions advanced by supporters of the inorganic synthesis of oil back in the last century. All these proofs and their lack of foundation have been considered in great detail in special literature. This allows us in the present report to limit ourselves to a brief mention of them. The basic propositions (not taking account of various indirect opinions) upon which the supporters of the inorganic synthesis of oil rely are the following:

1. The presence of oil or signs of it in igneous and metamorphic rocks.

It is true that about thirty productive or semi-productive oil deposits associated with igneous and metamorphic rocks are known; in addition there is mention of more than two hundred cases of hydrocarbons included as minerals within igneous or metamorphic rocks.

An analysis of the geologic circumstances of the existence of such oil deposits or the appearance of hydrocarbons in connection with igneous and metamorphic rocks (where it can be based on sufficient factual material) without any doubt establishes their formation in connection with sedimentary strata or allows such a possibility. It remains to be emphasized that in general such phenomena are characteristic not of the igneous or metamorphic rocks themselves but rather of their zones of contact with sedimentary strata.

2. The regional association of accumulations of oil and gas and their appearance in connection with shields (V. B. Porfirev) and zones of rupture in the earth's crust.

Such an association is mythical. The geographic location of more than ten thousand presently known oil and gas deposits and many thousands of natural appearances of oil and gas without any doubt demonstrates their association with sedimentary basins, including zones of rupture, if such are found in these basins. This fact is so obvious that it hardly requires further consideration.

3. The presence of fuel gas in the composition of contemporaneous volcanic gases.

In present-day volcanic gases it has been proven that there is a negligible amount of methane only. Considering, in addition, that the craters of many volcanoes are situated among sedimentary rocks, one should not be persuaded that the discharges of methane are connected with magma and not with the sublimation of organic matter in sedimentary rocks.

4. The presence of hydrocarbons in the atmosphere of the sn and the great planets has been observed. From this stems the proposition that hydrocarbons were formed in the atmosphere of the earth's globe during the "astronomic" period of its development.

In the views of Schmidt's theory of cosmogony the presence of light gases, including methane, in the original atmosphere of the earth and the other planets of the terrestrial group is excluded. Even admitting the molten-liquid condition of the earth and the presence of methane in its atmosphere, one must not expect the ebsorption of methane by cooling magmas. In the crystallization of magmas the gaseous phase within them attempts to separate itself. The absorption of gases by already crystallized magmas is possible only as a result of their occlusion by the earth's surface having become hardened in the highest degree.

5. The possible synthesis of hydrocarbons by inorganic means is proved by a series of very simple chemical experiments already carried out in the last century.

The chemical experiments that have been carried out (a summary of them is presented in Belikov's work) do not correspond to the conditions that could be observed on the Earth at any stage of its development. Furthermore, a thermodynamic analysis (M. F. Dvali and P. F. Andreyev) of the conditions of flow of magma while it is being intruded into the earth's sedimentary layers bears witness to the fact that hydrocarbons more complex than methane can neither arise nor exist within it.

One's attitude toward this or that scientific hypothesis ought to be determined not by opinions as to the originality of the ideas expressed in it, but by its correspondence to the facts and by its practical applicability. This very applicability can itself be the criterion for evaluating this or that hypothesis. To what extent does applicability support the hypothesis of the inorganic synthesis of oil, to what extent is this hypothesis justified by its practical results, and, finally, to what extent can the conclusions drawn from this hypothesis be used in practise?

It has already been remarked above that the factual data obtained as a result of practical work are in sharp opposition to the hypotheses of the inorganic synthesis of oil. Only about thirty deposits, out of more than ten thousand, can be drawn upon by the proponents of inorganic synthesis in support of their views, and these only after a one-sided consideration of them.

Regardless of the originality of the various hypotheses of the inorganic origin of oil, they have never been used in practise in the search for oil and gas. In the latest modifications of the inorganic hypothesis of the origin of oil its adherents N. A. Kudryavtsev, P. N. Kropotkin and, most recently, V. B. Porfirev, trying to base on practical applications, separate the conditions of formation of oil itself from the circumstances of formation of its deposits. The first they associate with magmatic centers or subcrustal depths, and the second with sedimentary strata. In this connection it must be stressed that as long as the formation of oil deposits takes place within sediments, the direction of exploratory activities and their methodology should not be changed, but must be the same as applications based on the organic theory. It is necessary, according to their view, only to drill down in each region to the greatest depth technically possible and to uncover the basement. In such a formulation one very distinctly sees a desire to tear theory away from practise, an attempt to prove that the development of theory is not necessary for the advancement of practise, and an attempt, characteristic of various theories, not to base on the results of practical work. Whether they wish to or not, all the adherents of the inorganic hypotheses of whatever tone or shading, in proceeding to the conditions under which

oil and gas deposits are formed, are compelled to connect this with zones of fracturing.

In this connection it is of interest to cite the following calculation by G. M. Knebel: out of the primary reserves in 236 of the greatest deposits of capitalist countries (enclosing within their depths 82.5 reserves of oil in capitalist countries) only 1.2% of the reserves are connected with zones of faulted deposits.

Thus the inorganic hypotheses of the origin of oil contribute nothing to practical exploration and prospecting work (if they are adapted to real practical work at all) or, what corresponds more closely to actuality, these hypotheses can only disorient practical work.

THE CHIEF POSITIONS IN PRESENT-DAY THEORY ON THE ORGANIC ORIGIN OF OIL

The basic positions of the theory of the organic origin of oil are set forth in the collection "The Origin of Oil", drawn up by a group of co-workers in VNIGRI and VNIGNI as material for a report by the Orgkomitet and published by Gostoptekhizdat in 1955. These positions are as follows.

Circumstances Pointing to the Biogenic Origin of Oil

1. The composition of oil. The chemical composition of oil and other organic fuel rocks have much in common. Oxygen, nitrogenous, sulfur and other compounds contained in natural oil by their own composition and properties bear witness to the biogenic origin of oil.

2. The isotope composition of the carbon in oil is the same as that of the matter in the organic world; it is different from the isotope composition of the carbon in carbonates, igneous rocks and other inorganic compounds.

3. Experimentally under laboratory conditions it has been confirmed that it is possible to alter organic matter in the direction of oil formation.

4. The fact that an absolute majority (99.9%) of the discovered deposits of oil and gas are associated with normal sedimentary formation.

5. The absence of any signs of the appearance of oil and gas in regions of shields and large projections of crystalline rocks, where they are not in contact with subaqueous sedimentary formations. Within the areas of the greatest extent of the Guiana, Brazil, Baltic, African, Indian, and Arabian shields there have been found neither accumulations of oil and gas, nor even more-or-less clear appearances of them.

6. The connection according to the laws of nature of the processes of oil formation and the accumulation of oil and gas in the course of separate periods of the geologic history of the earth's crust with the accumulation and transformation of organic matter stored in deposits of a given period.

This connection is very graphically illustrated by the curves constructed by V. A. Sokolov, in which are shown the retention of organic carbons in the sedimentary rocks of separate geologic periods and the deposits of coal and oil produced in them. Similar curves constructed by N. S. Mustafin illustrate the distribution of the world's deposits of fuel minerals — coal, oil-shales and oil — along large stratigraphic units.

7. The association of regional gas and oil bearing stratigraphic complexes in all matrices with definite types of formations of subaqueous strata characterized by a steady submergence of the sedimentary basin in the period of geologic history under consideration. This indicates that the process of oil-formation in the lithosphere is connected with a definite condition of tectonic oscillatory movement of the sedimentary basin and with definite paleogeographic, lithofacies and biochemical conditions of accumulation and sedimentation in a given basin. The above is confirmed by very many facts using the basic gas and oil bearing regions of the world as examples.

8. The presence of liquid hydrocarbons of the oil type in contemporary and early Quaternary marine sediments and

their increasing retention in the process of transforming organic matter is a direct proof of the generic connection of oil with original matter of organic derivation. This point is elaborated on in somewhat greater detail below.

The Problem of the Original Material and the Conditions of its Accumulation in Sediments

1. The conditions of the transformation of original organic matter in the stages of diagenesis.

Works of recent years produced since 1947 in the USSR (a group under V. V. Beber with the participation of A. I. Gorskaya and others) and begun a few years later in the USA (Smith), have presented new material on the composition and transformation of organic matter in contemporary and Quaternary marine sediments. As a result of these works the possibility has been proven of a significantly greater concentration of the bituminous part of organic matter than had been believed earlier, according to Trask's data; specifically, in dry-weight sediments up to 0.2 - 0.9% and in reckoning organic matter up to 16%.

In the conditions of transformation in reconstructed sediments were observed significant features of this bituminous part of organic matter and its transformation in structure and composition towards oil. In this relation was shown an increase in the retention of the fatty part of bitumen. In the bitumen of plankton from the Black Sea 38.9% is retained; in bitumens of Black Sea silts in the zone of hydrogen sulfide contamination 42.5%; in bitumens of ancient Black Sea silts of the same facies, 55%. In connection with another (benthic) character of the original organic material in silt and sand-sized deposits of the contemporary Caspian, in shallow-water facies, the content of fats in their bitumens is on the average 26.1%. In the process of transformation this content is sharply increased to 34.3% in the silts of the upper layers of the ancient Caspian and to 52.7% in sands grading into the Bakinskii layer (lower-most post-Bliocene).

In the same direction, from the original organic matter to contemporary and even farther to lower Quaternary sediments, in the elementary composition of bitumen the content of carbon and hydrogen is increased and the oxygen content is decreased. Especially characteristic in this decrease is the relation C:H. As a result the most reduced bitumens in sediments of the ancient Caspian display the following elementary composition (in %):

	C	H	O & N
Clays. . . .	80.0	10.5	9.5
Sands. . . .	80.0	10.9	9.1

These bitumens must still lose about 5 - 7% of oxygen in order to reach the elementary composition of oil. Nevertheless a complete correspondence in the exponents of bitumens between Quaternary marine sediments and oil is very little likely, since it is difficult to suppose that all the bitumen is entirely transformed into oil. The method of extraction of bitumen that is being applied is also significant. In a given case the bitumen was separated with benzol from the spirtobenzol extract and was correspondingly to a greater degree laden with acid components than bitumen extracted directly from the rocks with benzol or chloroform. In the exponents of chloroform extracts the gap between the most reduced bitumens of Quaternary marine sediments and those of oils will be significantly narrower.

It is known that the bituminous part of the original organic matter of any origin at all contains a very small amount of hydrocarbons, for example from 1.6% in the bitumens of marine benthic vegetation to 6.2 - 7.2% in plankton bitumens. Newly acquired data indicate that in the process of transformation of the organic matter in sediments the hydrocarbon content (including also bitumen) is increased several times as a result not only of what is built up by accumulation but also through new formation. At the same time the composition of these very hydrocarbons is also changes: in the early stages of the process these hydrocarbons are predominantly naphtha-methane; in the later stages the relative content of their aromatic fraction gradually increases. A. I. Gorskaya and later Smith ascertained the chemical and physical characteristics of the hydrocarbons in Quaternary marine sediments.

Only a very small amount of these hydrocarbons is solid; for the most part they have the appearance of a lightly tinted, transparent and greasy liquid. Sometimes they are even volatile hydrocarbons discovered in the distillation of solvents from bitumen. The empirical formulas of the predominant fractions in the hydrocarbons are the following: $C_{14,58}H_{27,12}$ (ancient Caspian), $C_{18,86}H_{32,85}$ (Black Sea), $C_{18,73}H_{37,6}$ (Gulf of Mexico), $C_{23,96}H_{46,3}$ (Pacific Ocean at California).

The increase in the content of hydrocarbons, (reckoning on the basis of bitumen and the dry weight of sediments), is proved by the correspondence between data obtained in two different Quaternary basins of sedimentation: the ancient Caspian and the Gulf of Mexico. In both cases in the process of transformation, from the upper layers of the section to the lower, the hydrocarbon content in bitumen increases from 7.5 - 11.5 to 21-31% or, reckoning from the dry weight of the sediments, from 0.002 - 0.006 to 0.01 - 0.03%. At the same time there is an increase within the sum of hydrocarbons of the content of aromatic hydrocarbons, for example for the sediments of the ancient Caspian from 8.2 - 8.8 to 23-26%. Similarly, according to data from infra-red and ultra-violet absorption spectra (E. A. Glebovskaya), the hydrocarbons of Quaternary marine sediments acquire more and more of the qualitative characteristics of oil hydrocarbons. In the aggregate, from these data one may speak of the oil-like character of these hydrocarbons and the phenomena of their new formation, in the first instance, apparently, at the expense of decarboxylizing the acids of the fatty part of bitumen, the content of which decreases in parallel manner.

Thus, under reducing conditions in sediments, one can observe the reduction of bitumens, their approach in elementary and component content to oil, and an increase in the concentration of oil-type hydrocarbons.

It is impossible not to see in this process a definite trend toward the formation of oil.

There is another tendency in the process under oxidizing conditions in deposits. In these conditions the bitumens are to a significant degree enriched with more acid components. In comparison with the previous bitumens there is here a sharp reduction in the hydrocarbon content of the bitumen, while the acid content of the fats is increased. That is, the formation of new hydrocarbons, apparently, does not take place, and the hydrocarbons present are only those left over from the original material. The process of transformation of the bitumens goes on in a different direction that is notably divergent from or even the opposite of the path of oil formation.

A very real source for the formation of new hydrocarbons is the more reduced components of bitumen — fats and benzol resins. A series of experiments, however, performed by T. A. Simakova and A. I. Gorskaya, shows that in de-bitumenized material (for this experiment the water-plant Cladophora fracta f. marina was taken) under the influence of the anaerobic biocoenosis of bacteria there is a complementary formation of these bituminous components. I conjunction with the data from an analytical investigation of natural specimens of Quaternary marine sediments this indicates the participation in the formation of new bitumen (an hydrocarbons) of other fractions of organic matter. It is natural, therefore, that the 0.03 0.06% concentrations of hydrocarbons observed in Quaternary marine sediments are not in any way the limit of the possible content of disseminated hydrocarbons in oil-bearing sediments.

At the same time the process of reduction of bitumens with the formation and accumulation of hydrocarbons of the oil type can be interrupted and pass over into oxidation, just as subaqueous conditions in a basin of sedimentation can change to subaerial. This can be easily seen from a comparison of the characteristics of bitumens from one and the same deposits of the ancient Caspian, in the open boreholes of marine oil-wells, and in holes in dry sediments. In the dry holes, in connection with secondary processes of oxidation, there is observed a change from negative amounts of oxidation-reduction potential to positive; in the organic matter of the sediments there is a sharp increase in the content of humous matter; and in bitumens the content of more reduced

components (fats and benzol resins) decreases while the content of the acid components of bitumen increases. There is also a significant decrease in the hydrocarbon content of bitumen. By all there indices bitumens display clear features of oxidation when the bed of sediments being formed is freed from its cover of water. Put in another way, in order to secure the necessary trend in the process of altering bitumens in the direction of oil, there must be a steady submergence of the sediments within a contained, subaqueous environment of sedimentation.

2. The conditions of accumulation of the original organic matter within sediments.

Widespread recognition has been given to A. D. Arkhangelskii's point of view on deposits of the original organic matter of oil in an environment of clay sediments in contaminated shallow-water facies.

I. M. Gubkin has given the question a broader treatment. According to his opinion, oil can also originate in the littoral facies of partly enclosed bodies of water (lagoons, estuaries, gulfs) and in the shore facies of the open parts of marine basins. I. M. Gubkin has not expressed an opinion on the possibility of accumulation of original matter in clay sediments growing here, but in regard to sandy and carbonate deposits Gubkin has left the question open up to now, as long as no proofs can be adduced "that in sands and limestones there can take place an accumulation of organic matter on a large scale." (Study of Oil, p. 52, 1932)

New data (V. V. Beber and co-authors, 1956) indicate the real possibility of heightened concentrations of organic matter not only in clay, but also in sand and silt sediments. Such possibilities arise not only in the course of sedimentation (in lagoon and gulf facies, following the complete decomposition of ground vegetation into a formless mass and the simultaneous importation of terrigenous material of varying granulometric composition), but also as a result of the secondary enrichment of sands and silts by the mobile part of organic matter from overlying silt deposits that are rich in this material; the latter case is spread also to the facies of the open parts of marine basins under the conditions of frequently alternating different sediments.

A generally accepted position is that of the necessity for reducing conditions in sediments in order to obtain the necessary trend of alteration of organic matter in the direction of oil formation.

It has been established (V. G. Savich, 1950) that the composition of this or that environment in sediments — oxidizing or reducing — is influenced not by the granulometric composition of the sediment (sand, silt or clay) but by the nature of the paleogeographic surroundings and the relative degree of concentration of organic matter in the sediments. Hence the need to distinguish the appearance of reducing conditions from the limits of basins contaminated by hydrogen sulfide.

There is a corresponding definition of the volume of the facies necessary for the accumulation (and later transformation) of the original organic matter of oil. This is pertinent to the facies of lagoons and shallow-water marine gulfs, of the shelf of the open parts of marine basins to the depth of the greatest development of plankton, and, from the number of deeper-water facies, to that of H_2S contamination in thin layers of the upper (oxidizing) zone of the water. The same favorable conditions may arise within continental basins. In the conditions of carbonate facies, along with the indicated environments, the portions of the sea behind barrier reefs and within reefed islands are also worthy of attention. It is very possible that this list is far from complete.

It is evident also that the above enumerated physico-geographic environments arise within a definite geotectonic situation within the given basin of sedimentation. For terrigenous facies, evidently, an alternation of sand-silt and clay sediments is the most favorable for the accumulation of original organic material as well as for its succeeding transformation. Various physico-mechanical conditions in the deposits can have unequal influence on the process of the farthest-reaching transformation of organic matter. In the sand-silt deposits of the ancient Caspian a relatively higher content of bitumen in the organic

matter has been found than in the clay. In several cases the bitumens of sand-silt deposits are characterized by greater reduction in comparison with the bitumens of mixed (in section or in horizontal distribution) clay deposits. Doubtless the number of observations is still insufficient. Further investigations are needed for final confirmation of the data thus far obtained.

The means by which organic matter is altered, leading to the formation of oil, and the factors defining the stages and direction of such alteration.

It is well known that the concept of "original organic matter" varies widely with the views of the person investigating the conditions under which oil is formed.

There are differences on the question of concentration — from the highly enriched almost pure accumulations of organic matter, of the coal type, featured in V. B. Porfirev's hypothesis, or the strongly enriched varieties like oil shale (according to A. F. Dobryansky's hypothesis), to rocks comparatively poor in organic matter, which answer to the norms of the theory of oil-producing suites.

The difference in views is partly in the facies-character of the organic matter — from typical (sapropelitov) mixed with basic fatty material, to primarily humous varieties of fresh-water (sapropelyei) which were observed by A. F. Dobryanskii in the quality of typical oil-forming organic matter.

There is a difference in views in the matter of evaluating the roles in the oil-forming process played by different elements in the composition of the organic matter. According to the most widespread opinions, the chief source of oil hydrocarbons is the lipoid components.

Some authors (A. F. Dobryanskii, V. A. Sokolov) assert that in the process of posthumous alteration of organic material all the components in it lose their individuality, and the reduced mass of organic matter emerges as something homogeneous. Similar suppositions answer to the scheme of gross transformation of organic matter to oil.

Significant differences in the views regarding the problems of oil-forming organic matter exist in the question of the amount of oil produced as a per cent of the general mass of original organic matter.

The adherents of one group of hypotheses (V. B. Porfirev, A. F. Dobryanskii, G. L. Stadnikov, K. P. Kalitskii, etc.) describe the formation of oil as a process of gross transformation of the whole sum of original organic matter into volatile products; supporters of the theory of oil-producing suites consider oil formation as a process leading to the mobilization of only a small portion of the original organic matter. Regarding this, it must be said that, with the increasing accuracy of our knowledge of the nature of disseminated organic matter, the amounts characterizing the size of this portion become smaller and smaller. For example, in A. D. Arkhangelskii's and P. Trask's representations it was expressed in figures up to 10% (2 - 4%) and more of the organic matter. According to the representations most often argued today it rarely exceeds the limits of 1 - 2%.

The enumerated features of the difference, touching upon only one aspect of the problem of oil formation — the question of oil-forming organic matter, may be traced back in all their variety in analyzing the views current at the present time. But this variety does not at all bear the character of random combinations.

The supposition of gross transformation of the whole sum of organic matter into volatile products normally is joined to the concept of the high enrichment of oil-producing rocks by organic matter. In this connection it is completely natural that there should be a lessened demand for the selection of those concrete elements in the material composition of the original matter which give the beginnings of oil.

All these interrelated peculiarities of the geochemical scheme correspond in the geologic concept to the idea of oil formation in situ. The process of oil formation in situ set forth according to this scheme is required: 1) in high concentrations of the original organic matter, obtaining a normal saturation of the collecting rock,

2) in the gross non-stop alteration of the entire sum of organic matter into volatile products, and 3) allows a lower requirement in the material composition of the original organic matter.

The diametrically opposed geologic scheme of the formation of deposits as a result of the accumulation of the disseminated hydrocarbons, naturally, eliminates the need for high concentrations of the original organic matter and for great degrees of transformation into volatile products, since depending on the dimensions of the oil-collecting space the requirements for the emergence of oil from the single space or volume of producing rocks can be more or less modest. Along with this there can be higher requirements for certain selected elements in the material composition of organic matter to the extent that there is an inconsiderable portion of the general mass of the latter.

There is still one essential difference between the two considered trends of thought in the question of the genesis of oil. This difference touches on the interrelationship between the processes of oil and coal formation.

It is not hard to show that the concept of the gross transformation into volatile products of the entire mass of decayed organic matter in the source rocks corresponds to the view of oil formation as a special type of transformation of organic matter, not to be connected with that of coal.

According to this view, in one case the process leads to the formation of solid products not subject to alteration and made up of coal-like matter; in the second case it leads to the formation of liquid products fully capable of migration and not accompanied by insoluble coal mixtures.

The concept of oil formation as a process in which the generation of hydrocarbons takes up only a negligible part of the organic matter accumulated in the producing rock is in accord with the idea of oil and coal formation as two different aspects of a single process.

In the scheme of this system the suggested process, which produces the beginnings of oil, is to a great degree one of the formation of solid coal-like matter rather than of liquid hydrocarbons, since the basic mass of these products is a material closer to coal than to oil. Therefore from these positions oil-formation cannot be contrasted to coal formation as a process proceeding in the opposite direction. Rather it is considered as a process closely connected with coal formation in one overall transformation of accumulated organic matter.

The question of the factors in oil formation first of all demands a consideration of the basic sources from which can be formed the hydrocarbons entering into the composition of oil.

There are three chief lines of thought, as follows, on the formation of hydrocarbons in oil-producing rocks, corresponding to three different stages in the latter's existence:

1. The introduction into sediments of hydrocarbons in the living matter of the originating organisms. The reality of this source has been proven beyond doubt, especially by work done in recent years (A. I. Gorskaya, P. Smith).

2. The biogenic formation of new hydrocarbons (except methane) from non-hydrocarbon materials, under the action of microorganisms. The importance of this source has been little studied and by some authors is denied altogether. In this category of phenomena must be included also the processes of transformation of organic materials through the catalytic action of ferments within the living framework (M. A. Messineva, K. Zobell).

3. The catagenic formation of new hydrocarbons (aside from methane) from non-hydrocarbon matter and the reorganization of previously existing hydrocarbons through the action of raised temperatures and the presence of catalysts. This source is in practise denied by no one, but its importance is by some authors evidently regarded as little. The possibility of this process under natural conditions is argued on the basis of data from laboratory experiments. This phenomenon should also be studied under natural conditions.

The first of these enumerated sources corresponds to the initial stage of formation of oil-producing matter; the second source enters the diagenetic phase of sediments up to the point where bacterial life has still not died. The third source applies to the catagenetic phase of rocks in the period of their burial at depth. Thus at every stage of the development of a rock it is in principle possible for hydrocarbons to be formed in it and also for them in principle to be transferred to collecting rocks.

The majority of investigators admit that each of the enumerated sources plays a role in the formation of oil, but which of them is fundamental has not yet been clarified.

Some investigators attempt to connect the origin of oil hydrocarbons to only the first source, asserting that oil formation in actuality consists of the physical concentration of those hydrocarbons that are already synthesized in living matter.

In any case, on the basis of investigations by N. G. Ushinskii, T. L. Ginsburg-Karagicheva, E. D. Reinfeldt, A. A. Maliantz, B. L. Isachenko, W. S. Towson, S. P. Kuznetsov (in the USSR), K. Zobell and his collaborators (in the USA), it can be considered as proven that microorganisms play a great role in the decomposition of the organic matter contained in sediments, and in the creation in these sediments of a reducing geochemical environment favorable to the formation of organic matter in the direction of oil.

Work of recent years in VNIGNI has considerably clarified the role of biochemical factors in gas and oil formation. A systematic study of the distribution of microorganisms in rocks in section through a series of drill holes has shown the presence of bacteria in all rocks, the amount of these bacteria depending not on the depth of deposit of this or that stratum but on the content of nutrient elements in it.

G. L. Stadnikov, without denying a role to the first source in the formation of oil hydrocarbons, attaches very great importance to the second and third in the formation of oil hydrocarbons.

A. F. Dobryanskii, on the other hand, is inclined to deny completely the first and second sources, stating that hydrocarbons are not formed until the oil-producing rocks are fallen into the catagenic zone.

Similar views on this process have also been expressed by V. B. Porfirev. In this connection the first author cited defines the formation of oil hydrocarbons as a typical process of thermal disintegration carried out under heightened temperatures, whereas the second considers oil formation as pyrolysis in the zone of very high temperatures.

Oil formation is also connected with processes of thermal disintegration of organic matter under very high temperatures by J. Roberts, the author of a hypothesis which he calls the "metamorphic-distillation theory".

Suppositions of such a type are far from generally accepted. In the majority of the hypotheses produced it is assumed that processes of oil formation proceed under very low temperatures. There is a small number of works devoted to the establishment of this position (A. F. Frost, S. N. Obryachikov, S. P. Mironov, B. Cox, W. Brooks, U. Link, etc.). Here the proof that the temperatures of oil formation have not exceeded certain comparatively low limits has often been found in the presence in oil of various thermally unstable molecules. Though acknowledging in principle the justice of this observation, we must consider that it can be applied only to those thermally unstable molecules which are not a part of the final products formed in the hypergenic phase of the natural history of oil.

To the extent that, in the conditions of the existing differences in views, the question of the genesis of these or other components of oil does not achieve a simple solution, the arguments based upon it cannot but lose their absolute value, since they will be only at second remove from the truth of this or that hypothesis.

In the light of data on the inalterability of the composition of oil under the influence of the geochemical environment, attempts to calculate the temperatures of oil formation on the basis of data on the

composition of its light fractions (A. V. Frost, S. N. Obryadchikov, G. D. Halpern, etc.) have an even more conditional character.

Some investigators assign an essential place among the factors in oil formation to the energy of radioactive transformations (M. S. Karasev, R. Birs, K. Shepperd). Evaluation of this factor is based on general considerations, theoretical calculations and purely laboratory experiments.

Experiments carried out under laboratory conditions (Yu. Beger, Stennard, Whitehead and others) have shown that, under the action of radiation from radioactive elements, the disintegration of organic molecules is accompanied by the formation of gas-forming hydrocarbons of the oil series.

Evidently it can be considered as established (V. A. Sokolov) that processes of radioactive transformation do not play an essential role in the formation of oil.

From the chemical point of view the process of oil formation is one of the formaterials belonging primarily to the hydrocarbon system.

The two differences in principle in the views on the conditions of oil formation, as considered above, come essentially to this: is there a complex of matter, called oil, that is the product only of chemical alteration in situ, or does it arise through a combination of chemical transformations and processes of physical differentiation and accumulation over great areas?

This difference is usually not felt with sufficient definiteness, since in its extreme form the idea of oil formation in situ has very few supporters. But either as a tendency or as a definite accent it can be observed in the views of many investigators. Usually it appears in geochemical conceptions and is only faintly expressed or totally absent in geologic schemes.

The inevitability of the transformation of hydrocarbons generated in producing rocks, for the formation of deposits, is asserted in practise in all the existing hypotheses of the organic origin of oil, even when it does not arise out of direct necessity from the particular conception of the conditions of oil formation.

The phenomenon of primary migration is described differently by various investigators, depending on how they resolve the question of the conditions of oil formation.

In principle the possibility of the transfer of hydrocarbons from the producing to the reservoir rock is a real one at various stages of hydrocarbon formation, from the moment of early diagenesis to that of the metamorphosis of the sediment, though the mechanism of transfer must doubtless undergo essential changes.

Primary migration in the stage of early diagenesis in still unconsolidated sediments is, on the basis of observations by V. V. Beber, fully a reality. It consists of the transfer of the more volatile parts of the bituminous matter in the sediment along with other organic materials that are capable of being moved in these conditions.

Some investigators are inclined to consider this process as a primary migration, assuming that the bituminous materials emerging from the producing rock end their migration only in the reservoir rock.

Other investigators perceive in this phenomenon a process similar only in principle to primary migration, and which does not exert an essential influence on the final events bringing about the formation of deposits. Primary migration is, properly speaking, connected with the catagenic phase of reorganization of organic matter, when the formation of the chemical aspect of the oil hydrocarbons must be completed and when, together with these, there must be formed great quantities of gas-forming products (carbonic acid, methane, etc.), the presence of which can play an essential role in the transfer of liquid hydrocarbons.

From the standpoint of views on the formation of oil in oil-producing suites, the matter of the accumulation of hydrocarbon molecules that have been formed

is no less essential. Depending on the connection of primary migration with this or that phase of the transformation of organic matter, the hydrocarbon molecules that arise end up in the reservoir rock in a disseminated condition. Their accumulation requires expenditures of energy, since, as calculations by V. F. Linetskii show, the forces of pressure are clearly insufficient to produce the necessary work of accumulation. The opposing forces in the strata are considerably greater than the forces of pressure.

Thus if in the theory of oil-producing suites questions of the possibility of transformation of the primary organic matter into hydrocarbon molecules can be considered as solved in principle, the questions of primary migration and accumulation in the reservoir rock of disseminated hydrocarbon molecules still call for a solution.

DIFFERING OPINION OF SPECIFIC SITUATIONS; UNSOLVED QUESTIONS AND QUESTIONS UNDER DISCUSSION.[2]

As is evident from what has been said above, many questions in the theory of the organic origin of oil have yet to be worked through, but the area of differing opinions and the discrepancy between them is becoming narrower year by year. A positive role in the development of the theory has been played by discussion carried on in print, bringing out many unsolved questions and directing investigation along definite lines. A discussion organized in 1957 in Lvov has been extremely useful. One of the most positive aspects of this was the entrance into the discussion of many workers in production, who stressed the importance for practical work of developments in theory and showed inescapably that in this practise they based themselves entirely on the organic theory of the origin of oil.

Another positive aspect of the discussion was V. B. Porfirev's recognition of the precariousness, from the geologic point of view, of the hypotheses he had earlier elaborated, and his departure from them.

An essential role in the development of oil science has been played by generalizations worked out in recent years (in the work of V. A. Sokolov, S. I. Mironov, I. O. Brod, N. A. Yeremenko, M. F. Mirchink and A. A. Bakirov, and others), which have supported results worked out at this stage of time.

Concrete investigations of recent years have been of great use in solving the question of the genesis of oil (N. A. Strakhov, V. V. Beber, N. B. Vassoyevich, Z. L. Maimin, P. G. Putsillo, M. N. Sokolov, L. A. Gulyayeva, K. F. Rodionova, V. A. Uspenskii, O. A. Radchenko, and many others.)

The chief discrepancies in views on this or that fundamental position in the theory of the organic origin of oil are basically related as follows:

Differing views on the question of oil-bearing sediments. In recent years, with the goal of clarifying the facies environment of the formation of suites containing oil deposits, important work has been carried on (in VNIGRI — N. B. Vassoyevich, Z. L. Maimin; VNIGNI — V. V. Beber, D. B. Zhabrev; AzNIGRI — D. B. Zhabrev; Oil Institute of the USSR Academy of Sciences — G. I. Teodorovich, L. A. Gulyayeva; Moscow State University — I. O. Brod; Geologic Institute of the Azerbaidjan Academy of Sciences — Sh. F. Mekhtiev, etc.) in studying the geochemistry of the rocks composing the various oil-bearing provinces.

Up to now, following the lead of A. D. Arkhangelskii and I. M. Gubkin, many investigators have assumed that only pelitic sediments — clays — can be oil-producers. On the other hand there are investigators such as, for example, V. A. Sokolov, M. M. Charygin and V. V. Beber, who believe that sedimentary rocks of any lithologic composition, including sands and silts, can be oil producing rocks.

Detailed geologic and geochemical studies of a series of oil-bearing regions, and extensive studies of the conditions of transformation of organic matter in

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[2]Based on works by M. F. Mirchink and A. A. Bakirov, published in the collection "The Origin of Oil", edited by M. F. Mirchink, Gostoptekhizdat, 1955.

contemporary and ancient Quaternary marine sediments have shown that the matter of attributing oil-forming conditions only to pelitic (clay) rocks must be reconsidered. Such ideas are being developed by M. N. Strakhov, B. F. Dyakov, V. V. Beber and others. Evidently, where there is an alternation of clay and sand-silt layers, the entire rock stratum can be oil-producing if, finally, the transformation of the original organic matter can take place in a reducing environment.

The discovery of a whole group of oil deposits in Devonian and Carboniferous carbonate rocks within the limits of the Russian Platform — rocks frequently excluding the possibility of long vertical or lateral migration of the oil — and the discovery of similar deposits of oil in the Caucasus, the Near East and other regions of the world underlines the correctness of contentions by V. P. Baturin, A. A. Bakirov, V. B. Tatarskii and a group of other investigators that under certain conditions carbonate rocks (limestones and dolomites) can also be oil producers. Another viewpoint is expressed by I. O. Brod, who believes that the rapid consolidation of carbonate sediments excludes the possibility of taking them as oil producers.

Among geologists the view is widespread that a major and decisive diagnostic feature of oil producing sediments is a high content of organic carbon (according to A. D. Arkhangelskii no less than 2%). This view, in the light of investigations by VNIGRI and VNIGNI, Moscow University and AzNIGRI, requires considerably greater specification.

As these investigations have shown, a high content of organic carbon (organic matter) in rocks, taken by itself, cannot serve as a decisive criterion for determining oil producing strata. The basic role is played not by this or that absolute quantity of organic matter, but by that part of it which in certain geochemical conditions is capable of forming oil hydrocarbons. It has been shown that in many regions, including ones without any prospect of oil, in a cross-section of sedimentary formations there are rocks with a high content of organic carbon. At the same time in other regions well known as oil and gas bearing, in cross sections of even the producing deposits, are found rocks (clay, etc.) characterized by a comparatively low (almost Clark's amounts) content of organic carbon; however in these regions there is a relatively high portion of the bituminogenic part of organic matter, right up to the presence of oil hydrocarbons.

Therefore, taking a high content of organic matter (organic carbon) in possible oil producing sediments as a positive factor, we cannot consider it as leading or decisive when taken by itself, except in conjunction with other properties of the sediments being studied.

In the light of new data obtained as a result of investigations by VNIGNI, VNIGRI, the Oil Institute of the Academy of Sciences of the USSR and other scientific investigative organizations, it is more correct to consider as oil producing sediments not just any uniform clay formations, for example, but a whole lithofacies complex of deposits (for example, an alternation of clay and silt, clay and limestone, etc., as was noted in one of the latest works by M. F. Mirchink and A. A. Bakirov). In this connection the chief features of oil producing rocks are: a) their accumulation in a water basin with a reducing geochemical environment, in conditions of fairly long-lasting submergence of the basin of sedimentation during the geologic period under consideration; and b) the presence in these sediments of a relatively high content of oil hydrocarbons in the bituminous part of the organic matter contained in the rock.

Differing views on factors determining the transformation of organic matter into oil or gas. The majority of investigators (geologists, chemists) at the present time place among the factors determining the alteration of original organic matter into oil or gas: the activity of microorganisms (the biogenic factor), pressure, temperature, the catalytic properties of certain rocks and the action of radioactive elements on organic matter.

In regard to the role and importance of microorganisms in the processes of oil and gas formation there is essential disagreement. One group of investigators limits the role of bacteria to participation

in the initial stages of decomposition of organic matter, considering that they can merely carry out the complete physical disintegration of organic matter and transform it into high-water colloids and, in favorable conditions, carry it on to complete reduction and changing of high-molecular fatty acids into paraffin. For the reconversion of these products of thoroughgoing reduction into typical oil structures — polymethylenic and aromatic — there must in principle be other powerful agents of destruction. (V. B. Porfirev).

Another group of investigators attaches great importance to microbiologic processes in oil formation.

The works of T. L. Ginsburg-Karagicheva, in which she set forth a scheme of bacterial formation of oil from organic matter, are well known. In a series of his own works Zobell confirmed that bacteria are capable of synthesizing hydrocarbons.

In the question of the roles of pressure and temperature there are differences of opinion on the absolute temperature needed for the beginning and development of the process of oil formation.

On the basis of data from experimental investigations the majority of investigators both in our country and abroad holds views according to which the process of oil formation in the lithosphere goes on under comparatively low pressures and temperatures.

As an essential argument for the hypothesis of the formation of oil in fairly low pressures and temperatures many investigators use the fact of the presence in oil of a whole group of organic, thermally unstable molecules, which cannot exist in temperatures greater than 250 - 300 degrees (data from investigations by A. V. Frost, S. N. Obryadchikov in the USSR; Treibs, Bailey and Kuhl abroad).

Some investigators hold other views. Thus V. B. Porfirev has picked out a stage of thermolysis in oil formation, believing that the formation of low-molecular liquid hydrocarbons, naphthas, aromatics and isomolecules defining the composition of genuine oil is brought about by thermal destruction at temperatures on the order of 300-500 degrees.

The importance of pressure in the process of oil formation is usually only postulated, and rarely appears in factual material. Thus far there are no direct proofs that pressure is of serious importance in the changing of organic matter into oil.

The role of the remaining physico-chemical factors, namely the catalytic properties of certain minerals, and also the energy of radioactive materials, in the transformation of organic matter in the direction of oil formation has been shown by experimental investigations done by scientists under laboratory conditions.

Investigations by a group of Soviet scientists (Academician N. D. Zelinskii, A. V. Frost, L. Ya. Larin, A. F. Nikolayeva, N. S. Sattarzade, A. F. Dobryanskii, AN. Bogolomov and others) and also of certain foreign scientists (B. Brooks and others) have proven experimentally the possibility of obtaining oil hydrocarbons from fatty acids and other products of catalytic action in clay sediments containing surficially active minerals at temperatures below 200 - 250 degrees (down to 65 degrees in Brooks).

On the basis of the investigations cited the role of the catalytic factor in the process of oil formation is at the present time acknowledged by the majority of investigators of this problem.

However the physico-chemical laws of catalytic action in containing rocks on the iniation and course of the process of transformation of organic matter into oil in concrete natural conditions have still been scarcely studied.

In recent works by M. A. Messineva it has been shown that the factor of fermentative catalyzing can play a very important role in oil formation. But many questions in the study of ferments still await their solution: the properties of fermentative action in rocks of various origins, connected or not connected with the process of oil formation, the syngenesis or new formation of ferments in rocks, reducing fermentative reactions and their relation to the character of organic matter, etc.

On the basis of all that has been set forth one can conclude that the physico-chemical essence and the mechanism of the action of factors aiding the iniation and development of the processes of oil formation require further investigation.

There is a basis for saying that in the transformation of the organic matter contained in sediments a great part is also played by internal sources of energy enclosed in the organic matter itself. It is above all a question of internal chemical energy related to the molecular reorganization of matter.

It is fully logical to suppose that for the initiation and development of the transformation of organic matter towards oil and gas formation, the necessary energy might come not from external sources alone. In this process a large role might belong to the huge reserves of chemical energy enclosed in the organic matter itself within the sediment (A. F. Dobryanskii, P. F. Andreyev, M. F. Dvali, etc.).

The activization of these internal stores of energy in organic matter arises, probably, in connection with the molecular and intermolecular reorganization of the structure of the material, originating in specific geologic, physico-chemical and geobiochemical conditions in the surrounding medium.

The mechanism and scale of action of these internal sources of energy enclosed in the organic matter itself, through definite stages of its transformation into oil, have been very little studied, and many sides of this question are still completely unclarified.

The development of some ideas expressed by Towson might turn out to be very fruitful. In Towson's view the transformation of organic matter into oil can be considered as a process of energy loss, accompanied by its redistribution and the rise of separate molecules with a great store of energy.

<u>The most important differing views on the question of the chemistry of oil formation and of the changes in the chemical composition of oil within the earth's crust.</u> Clarification of the Chemistry of hydrocarbon formation in the earth's crust is important above all for the clarification of the organic or inorganic origin of oil hydrocarbons and the temperature conditions of oil formation.

From a purely chemical point of view the question of the organic or inorganic origin of hydrocarbons still cannot have a simple solution, if only because almost nothing is known of the composition and structure of hydrocarbons obtained in experiments in the inorganic synthesis of oil under laboratory conditions; as for natural hydrocarbons, one can only not exclude the possibility in specific cases of methane having a magmatic origin.

On the other hand, in support of the organic origin of oil hydrocarbons there is the closeness of the chemical composition of oil to fuel rocks of definitely organic origin (coals, oil shales) and the presence in live organic matter of the same hydrocarbons as in oil.

The indicated analogy allows us to affirm that the formation of the fundamental hydrocarbon part of the mass of oil probably takes place in conditions of low temperature. If in specific oils admixtures of molecules are found that reflect the action of high temperatures, the final solution of the question will depend on the clarification of the geologic circumstances of the formation of such oil deposits (greater depth of the deposit, nearness of intrusive rocks).

From the chemical point of view the formation of oil is a process of forming matter that is primarily of the hydrocarbon system. According to suppositions which once enjoyed considerable popularity but at the present time have only a few adherents, this process is thought of as gross transformation of the whole mass of organic matter in oil producing rocks into oil, along with the mobile products that travel with it.

In the hypotheses of the gross transformation of organic matter, the formation of the hydrocarbon system known as oil is considered to be only a chemical process going on in a homogeneous mass of organic matter that is pure or contains admixtures of clay (catalysts).

According to views more widespread at the present time, oil formation is considered as a process taking place at the expense of only partial separation of the hydrocarbons from the mass of disseminated organic matter, at the same time as the fundamental part of the latter is retained in the producing rock in the form of solid hydrocarbon residue.

By these views the formation of the complex of oil hydrocarbons is seen as the result of interrelationship between the chemical transformation of materials and their physical fractionalization. Both these and other processes are accomplished in oil producing rocks suitably connected with the reservoir.

The trend of change in the composition of oil depends on the geologic conditions.

Under action by hypergenic factors oil becomes heavier and is enriched in resinous and cyclic elements. In the end carbonic acid and solid bitumens are formed; the latter through subaerial oxidation are humified and turn into water-soluble compounds.

With the action of catagenic factors there ensues enrichment of the oil by lighter fractions, methanization, and a decrease in the quantity of resinous matter. The final result is the formation of methane gas and graphite (or products near to them).

In rough outline both the cited categories of alteration in the composition of oil can be characterized as diametrically opposed trends; this, unfortunately, has been a source of many mistakes in understanding the true direction of alteration.

In interpreting the general character of the changes corresponding to the two lines indicated above, the views of the various investigators do not diverge in principle. But discrepancies in estimating the relative scales of this phenomenon stem from sharply opposed systems in their views. These divergences are especially prominent in the problem of the original type of oil.

According to the most widely accepted views this original type is a light, little-resinous, paraffin oil, rich in methane-like hydrocarbons.

This position is argued by the following data:

1. The hydrocarbons of disseminated organic matter, considered as diffued oil, are distinguished usually by a lower content of aromatic hydrocarbons compared to oil and by a considerable enrichment in solid hydrocarbons. Besides, in the course of primary migration, under the conditions of the process there must be a selective sifting out of the basic mass of resinous matter and the portion of aromatic hydro carbons.

2. Oils deposited in circumstances of the greatest isolation from the action of weathering are distinguished usually by a lower specific weight and richness in the lighter fractions with enrichment in parafin and the methane hydrocarbons in general.

Supporters of this system of views assert that heavy resinous oils lacking paraffin and rich in cyclic components are the product of oxidation-transformation of light, little-resinous paraffin oils.

This is argued on the following grounds:

1. In a section through oil deposits of many layers there is usually an increase in the weight of the oil toward the upper horizons; that is: as one enters the zone of greater activity of the hypergene factors. There is a parallel change in the composition of the water toward lesser metamorphism.

2. At the borders of various deposits one usually observes an increase in the weight of oil in the zone of contact with water.

3. The lack of sulfates in the waters accompanying oil by the reduction of the sulfates from oxidation of the oil. In the explanation of the mechanism of this phenomenon there is indication in the oil-water contact of a large amount of microorganisms that reduce the sulfates.

Those who represent the opposing view assert that the original type of oil is

a dense, resinous, highly cyclic malt or asphalt, whereas the lighter and less cyclic oils are the products of catagenic alteration (metamorphism) of this original oil.

This position is argued from the following reasons based on chemical and thermodynamic considerations, and also on experimental data in oil technology:

1. the fundamental mass of original organic matter (according to A. F. Dobryanskii), showing a humic character, has a cyclic structure, and its gradual alteration into liquid products must run through the stage of viscous bitumens;

2. the basic trend of thermal-destructive changes in the organic matter consists of the opening of the cycles and accumulation of aliphatic structures;

3. the interrelationship in the chemical composition of oils of various types considered as the result of thermocatalytic alteration of heavier oils into lighter agrees with corresponding observations in chemico-technologic investigations.

On the differing views on the questions of the primary movement (migration) of oil hydrocarbons from the original producing sediments into reservoirs. The question of the primary movement (migration) of oil hydrocarbons from the producing sediments to the reservoir rocks is one of the least worked out in the theory of all those connected with the origin of oil in oil producing suites.

Clarification of this question is essential: at what stage of lithogenesis does the process begin of transferring the oil hydrocarbons from oil producing formations into the reservoirs? In the opinion of some investigators this process begins already at the stage of early diagenesis of the sediment; according to others this process can originate only with submergence of the strata to a considerable depth and is in essence connected with the zone of catagenesis. The depths necessary for the process to begin are indicated by different investigators as varying from 500 to 2000 or more meters.

Wide currency has recently been achieved by the view of the many-phased nature of the migration process, whose strengthening and weakening can take place at various stages of geologic history, depending on different reasons. The most extreme views in this direction, expressed by N. B. Vassoyevich, N. A. Yeremenko and S. P. Maksimov, speak of the possibility of the continuation of this process in ancient strata up to the present time.

There has been no study at all of the physical circumstances in which the primary migration of hydrocarbons arises and what physical laws direct it.

There are still very few factual data sufficiently well founded on the results of field and laboratory-experiment investigations for the solution of all these questions.

No less important, as was noted above, is the accumulation of the disseminated hydrocarbon molecules that have entered the reservoir rock. This question in essence has still not been supported by detailed scientific study.

BASIC TASKS FOR FURTHER RESEARCH

The fundamental aspects of the complicated process of oil formation in the earth's crust, thanks to the uncreasing efforts of a great number of co-workers in a group of institutes, can for the most part in recent years be considered as clarified.

But not a little effort is still required to decide many debatable points: on the primary migration of oil, its accumulation, the diagnosis of oil producing suites and rocks, and so forth.

Besides this, the processes of transformation of organic matter into hydrocarbons of the oil series demand more detailed investigation. There is not complete clarity on the role of the specific internal factors promoting this process in the stages of synthesis, diagenesis and catagenesis. Much has still to be worked out in studying the composition of oil. Much is not clear in its transformation that depends on its age, geochemical environment, etc.

The list of questions still to be worked out is long.

Work on these problems must be undertaken at such a stage that one can clarify the formation of everything that is met in the nature of oil and gas accumulation.

Many important investigative labors on all the basic aspects of the problem of oil genesis have already been completed or are being carried on in scientific investigative institutes and also in production laboratories.

But all this in no way means that the theory of the organic origin of oil can not at the present stage of time direct the practise of geologic exploration and prospecting work for oil and gas, as several of our colleagues have tried to say.

Proceeding from contemporary knowledge of the genesis of oil, oil geologists in their practical work are achieving great successes, discovering more and more new oil and gas deposits, and even new oil and gas bearing regions in various parts of our country. These successes are the best proof of the correctness of this theory.

The path for further necessary investigations to explain all the aspects of the question of the genesis of oil, from the position of the organic theory, is clear.

Questions Requiring Further Study.

I. The study of the chemical and isotopic composition of oil. The study of oil in relation to the capabilities of contemporary technology is conceived along the following lines:

1. clarification of the individual composition of the lightest fractions;

2. study of the fundamental structural groups of hydrocarbons composing the highest temperature distillation fractions;

3. study of the structure and genesis of the asphalt-resin components; this task is especially difficult in view of the extraordinary complexity of the subject, the obscurity of possible lines of investigation and the need for preliminary detailed exploratory work of a methodologic character;

4. study of the isotopic composition of oil and gas in connection with the natural environment of its deposition in depths;

5. a special task is the study of the porphyrins and the micro-elements connected with them.

II. In the problem of the original material, the conditions of its accumulation and transformation. The absence of proofs of the presence of hydrocarbons in contemporary and Quaternary subaqueous deposits was one of the basic arguments set up against the organic theory of oil. This great gap in the theory in recent years has been filled by the work of V. V. Beber, A. I. Gorskaya, P. Smith and others. They have shown the genetic connection between oil and the original material of organic provenance.

It must be said that these investigators have not, however, worked on the study of the composition of gas-forming hydrocarbons in sediments.

Work by S. V. Bruyevich, N. M. Strakhov, V. V. Beber, M. V. Klenova and others in studying the bottom sediments of various bodies of water have made it possible to follow clearly enough the conditions of accumulation of organic matter in sediments of various facies, and even the geochemical processes going on in them during early diagenesis.

In spite of these great achievements of recent years, further and large investigations are called for.

There is need to continue on the broadest scale the study of bitumens in bottom sediments and in Quaternary deposits, so as to follow in detail the change in the composition of the hydrocarbons from the beginning stage of sedimentation through the whole cycle of diagenesis. Detailed investigations must be made of sediments formed in various facies conditions not covered by previous investigations, and also of various intra-continental non-marine basins (brackish and fresh water).

The whole complex of investigations

must be set up in such a way that, as a result, the following could be established: 1) what are the facies environments in which originate the processes of alteration of the organic matter in sediments into hydrocarbons of the oil series; 2) is the formation of oil and gas deposits possible in the facies of fresh-water basins; 3) does the transformation cycle of the bitumens in organic matter into hydrocarbons of the oil series come to an end in the stage of diagenesis, or does it also continue into catagenesis; 4) what composition in the organic matter can ensure the formation of oil hydrocarbons under natural conditions; 5) what is the role of the processes of primary migration of hydrocarbons during all the stages of diagenesis?

Besides this, investigations are desired towards revealing the character of the hydrocarbon bonds, with a calculation of the relationship of even and odd numbers of carbon atoms.

Such investigations require broad cooperation between institutes, and also the drilling of small holes to a depth of 200 to 250 meters in various bodies of water.

One must consider as independent questions the study of the alteration of the isotopic composition of the biogenic elements in sediments, rocks, and the fluids enclosed in them.

On the Factors Determining the Transformation of Organic Matter in Oil and the Balance of Energy in the Transformation.

The transformation of the original organic matter into oil is a process of reduction, for which an input or redistribution of energy is needed.

Different hypotheses of the origin of oil are also based on different sources of energy and on different mechanisms of the reducing process, in which this or that factor of transformation is put forth as the active agent. In a number of cases universality is attributed to certain factors.

One achievement of our country's science in the problem of the genesis of oil is its work on the independence of of separate factors and on the importance of the factors of transformation of organic matter in the balance of energy of the transformation.

For the development of the organic theory of the origin of oil, work must be done on a still greater scale than there has been up to the present time on the factors of transformation and its thermodynamics.

In the light of studies of the stages in the process of oil formation, the question of the role of the various factors is settled differently for the different stages of oil formation.

If in the first stages the dominating role belongs to biogenic factors connected with the conditions of early diagenesis, in the last stages emerge physico-chemical factors acting under the conditions of the zone of catagenesis.

As in all other questions in the problems of the genesis of oil, in that of the factors in oil formation the decisive arguments must be sought in the sphere of facts observed in nature.

Attempts to reproduce the process in the laboratory are useful in discovering the mechanism of the phenomenon and interpreting certain partial aspects of its trend, and so forth, and are expedient in connection with observations on natural materials, but cannot serve in any way as the only or chief means of proof.

The reality in natural conditions of phenomena that are based only on laboratory experiments, however thorough-going and numerous they may be, in the absence of direct observations on natural materials can always be placed in doubt.

In evaluating the contemporary position of the study of factors in oil formation it must be admitted that the greater part of the positive data on the concrete characteristics of the phenomenon are of the nature of laboratory experiments and not observations carried out on natural materials.

The above remark is especially true in regard to the role of thermocatalytic phenonmena, whose study in the laboratory

has had a large number of workers (A. V. Frost, A. F. Dobryanskii and colleagues, and others).

The great investigations of catalytic action made thus far (by N. D. Zelinskii, A. F. Frost, M. A. Messineva, A. I. Bogolomov and many others) do not permit us to draw final conclusions as to the scale of organic and inorganic catalyzation in sedimentary rocks.

The same can be said about the role of radioactive decay, which has been studied in laboratory investigations (at least in the works of foreign authors); observations on natural materials allowing us to make a concrete evaluation of the phenomenon are lacking.

As regards the role of the biogenic factor — the activity of microorganisms — there are insufficient investigations both in laboratory experiments and observations under normal conditions.

We must pay increased attention to laboratory work in studying the role of microorganisms and fermentative synthesis in processes leading to the formation of hydrocarbons. We must also organize the making of such observations on processes going on in contemporary sediments, which would allow us to decide without any doubt the question of the presence and scale of the biogenic formation of new hydrocarbons in natural conditions.

It would also be necessary to make special observations on natural materials, directed toward discovering the true role of temperature and clay catalysts in the transformation of disseminated organic matter.

These remarks can be applied to the clarification of the influence of clay catalysts on the course of metamorphism of organic matter or that of the formation of new hydrocarbons, in both its quantitative scale and its qualitative direction.

On the Problem of Recognizing Oil-producing Formations.

The solution of the question of the conditions of formation of oil-producing suites and rocks and their diagnostic indications has been given quite a lot of attention in recent years.

Investigations to clarify the composition of disseminated bitumen-bearing substances in rocks of various geochemical facies have been carried out by Academician N. M. Strakhov and K. F. Rodionova, V. A. Uspenskii, O. A. Radchenko, etc.

Works by L. V. Pustovalov and G. I. Teodorovich have been devoted to the classification of geochemical facies and their distinguishing features.

Broad, all-embracing mineralogic-geochemical investigations of the rocks composing the various suites in oil-producing geologic provinces, with the goal of revealing the diagnostic indications of oil producing suites, have been established by such institutes as VNIGRI, VNIGNI, the Oil Institute of the USSR Academy of Sciences, AzNINGR, the Geologic Institute of the Azerbaidjan SSR, and Moscow University.

All these works have yielded very valuable material and have allowed the establishment of a direct connection between oil bearing and certain specific geochemical conditions in suites.

But all these efforts have not been sufficient to work out the final diagnostic indications of oil producing suites. There are serious disagreements on a series of questions; these disagreements were brought out for the following reasons:

1. the amount of investigation of the geochemistry of terrigenous rocks and the study of disseminated bitumens is still far from enough;

2. the classification of the minerals in geochemical facies has not been fully worked out, as a result of which in practical applications there has been much contradiction and difference of opinion;

3. there is no single method of investigation in the study of the geochemistry of rocks.

The tasks of further research in the study of oil producing suites are the following:

1. To continue, in greater extent, the geochemical study of the rocks composing the sections of oil bearing provinces. The goal of this work should be the separation in sections of the oil producing suites and the establishment of their diagnostic features, and also the separation of zones of oil and gas formation.

2. On the basis of already existing materials, to work out a single detailed classification of the minerals of geochemical facies. Their diagnostic indices should reflect not only the composition of the authigenic minerals, but also the geochemical processes that have gone on in the periods of diagenesis and catagenesis.

3. To broaden the study of the composition of disseminated bitumens, which according to existing data are related not only to the geochemical environment but can also depend on their history and on the nature of the original organic matter.

All these investigations require the working out of a series of methodologic questions.

Questions of the Formation Genetic Types of Oil

The question of the genetic interrelationship between the various oils is connected directly to the problem of the original type of oil. In this matter, as has already been mentioned, there are two extreme groups of views, diametrically opposed in their general evaluation of the direction of the alterations undergone by oil.

Further development of work to the end of revealing the actual trend of alteration is necessary.

In the study of materials in nature it may be necessary to make a wider and fuller comparison of the laws of oil composition with those of the properties of the surrounding environment (water, rocks, structural-geologic conditions, temperature, etc.).

In the area of laboratory experimental investigation it will be necessary to develop work on the anaerobic bacteriologic oxidation of oil in various materials, under various conditions, and by the action of various organisms.

The Study of the Geologic Laws of the Storing of Oil and Gas Deposits

Work in recent years in studying the laws of distribution of oil deposits has shown that oil and gas accumulate in regional zones in areas of great and long-lasting submergence in the earth's crust. These ideas have been expressed by Academician I. M. Gubkin, V. V. Beber, M. F. Mirchink, I. O. Brod, etc.

Recent work by I. O. Brod and N. A. Yeremenko, V. E. Khain, A. A. Bakirov, N. Yu. Uspenskaya, and A. Ya. Kreme has established a classification of these huge oil-bearing regions.

These works are the beginning of the development of a given direction of investigation and must be continued, with the mandatory participation of producing geologic establishments. Work is especially necessary in the detailed study of the tectonic processes within specific oil bearing regions and their relation to the location of zones of oil and gas accumulation.

In spite of a rather large number of unclear and still-discussed questions, the problem of the origin of oil has in recent years been solved in its essential aspects. There is no doubt of the organic origin of the overwhelming majority of the known accumulations of oil and gas. The possibility of the transformation of organic matter and various of its components into oil has been proven. It has been established that the changing of organic matter to oil can go on by various paths and through various factors. There is needed a quantitative evaluation of these processes and the discovery of the role and importance of the established factors of transformation applied to concrete geologic circumstances. In this aspect we must not omit from the area of study the inorganic synthesis of hydrocarbons. If the processes of transformation of organic matter into oil have to a considerable degree been studied and clarified, the processes of migration (especially primary) and accumulation still await their solution. These very processes of migration and accumu-

lation are now the least clear in the problem of the origin of oil.

The successful solution of many unclear questions in the problem of the origin of oil allows us to hope that the unsolved and still-discussed questions of this problem will also soon be solved by the co-ordinated work of scientists of the whole world.

Review Section

Belousov, V. V., FUNDAMENTAL PROBLEMS OF TECTONICS[1], The State Geology and Conservation Publishing House, Moscow, 1954, 606 pp. A Review by Mark Burgunker.

The scope of tectonics is specified as extending over the study of individual structures, and the study of regional distribution of such structures. The field also includes the study of the specific manner in which these individual structures and distributions come into being.

The "Russian School" of tectonics is described briefly in an early portion of the book. This school originated with A. P. Karpinskii; its fundamental tenets are that the major cratonic and geosynclinal regions are bounded by great fault systems, and that the major crustal movements consist of vertical displacements along these systems. Belousov also states that a radical genetic approach and the principle that there is an intimate causal relationship among all geological processes constitute other tenets of the "Russian School". In general, the primary role of horizontal stresses is denied (the primary tectonic stresses act vertically) and primary folding is treated as an integral aspect of vertical movement along abyssal faults.

Gravity and radioactivity are indicated as the primary sources of the earth's energy.

Belousov then turns to the study of individual structural forms. In a section devoted to nomenclature, he confines the term "structure" to an individual product of deformation; he indicates, further, that the criteria of structural form with which he is concerned derive from the study of layered rocks. His approach to fault nomenclature is based on the principle that pure slip or dip displacements do not exist; he, therefore, suggests slip-normal faults and slip-reverse faults as typical of the simplest categories for a legitimate nomenclature.

A rather detailed treatment of Quaternary tectonics, in the USSR, constitutes an interesting section of the book. He distinguishes the following sections:

1. An area of intensive Quaternary uplift (Fennoscandia, Taimyr and the Novo Sibir Islands);

2. Areas of intensive linear uplift with intense associated faulting and subordinate subsidence (Caucasus, Tien Shan, Eastern Sayan, Stanovoi Range);

3. Areas of less intense linear uplift with faulting along ancient surfaces (Carpathians, Western Sayan, Kopet-Dag, Soviet Far East);

4. Regions of very weak linear uplift with very weak subsidence along ancient faults (Urals, Mugodzhar, Ulu-Tau Chingiz Range);

5. Regions of very weak uplift (Siberian Craton, Donbas);

6. Regions of weak linear uplift (northeastern Kazakhsdan, southern and arctic Urals, Amu-Darya Valley);

7. Regions with apparently "compensating" uplift and subsidence (west Siberian Lowland and various portions of the European USSR).

It is shown, further, that the distribution of sedimentary thicknesses is far more stable, in geologic time, than the distribution of lithofacies. Thus, the distribution of thickness maxima on the Russian craton remains the same from the lower Carboniferous through the Permian (in the Urals foredeep and in the Manych-Donbas trough).

The major crustal movements are divided into two fundamental classes:

[1] This book is currently being translated under the auspices of the AGI Translation Center and will be published during the second half of 1959.

geanticlinal migration and simple regional oscillation. It is shown, also, that the great cycles of geologic history are complicated by subordinate orogenics; the great cycle which opened at the beginning of the Cambrian and closed at the end of the Silurian, for example, was complicated by marine regressions at the end of Cambrian and Ordovician time.

It is pointed out - in the discussion of the geologic history of Central Kazakhstan and Western Siberia - that the Paleozoic rocks of this area can be divided into two complexes: the lower complex consists of clastics and limestones; it may attain a thickness of 9 km. in the Chingiz Valley. It is suggested that these sediments were laid down in a subordinate geosyncline within a large geosyncline.

Belousov considers the evolution of cratonic regions. He suggests that the time between the Proterozoic and the present may have been a "transition period" during which a great portion of the surface of the earth passed geosynclincal conditions to cratonic conditions.

Belousov then turns to a discussion of lineation. He points out that lineation is possible if (1) the rock which assumes the orientation undergoes plastic deformation, and (2) if the "stream-lines" of the deformed rock are characterized by different velocities, which permits a rotation of the mineral grains. Plastic flow is also indicated as the fundamental mechanism of folding; this requires the assumption that sedimentary distribution (in point of thickness) also represents a pressure distribution.

The relationship between folding and faulting is then reviewed; the following sequence of deformation is proposed: (1) folding, (2) normal and reverse faulting, (3) regional uplift, (4) tension faulting and (5) normal faulting.

Nalivkin, D. V., A STUDY OF FACIES: THE ENVIRONMENT OF DEPOSITION [1], The Department of Geologic-Geographic Sciences, the Academy of Science of the USSR. Moscow and Leningrad, 1956, vol. I, 534 pp.; vol. II, 393 pp. A Review by Mark Burgunker.

The "facies" is defined as that complex which consists of a uniform lithologic unit and the fossil animals and plants which it contains. The distinction between lithofacies and biofacies, therefore, is rejected. Such concepts as that of a coal facies or a lagoonal facies are also rejected, inasmuch as the requirement that the lithology be uniform cannot be satisfied in the case of the entire sequence of deposits laid down in the course of the history of a lagoon or a coal basin. Again, Klenova's distinction between "transgression sediments" and regression sediments" is rejected; the lithologic differences between (let us say) "transgression sands" and "regression sands" would inevitably be too minor to appear among the petrographic data. Thickness and lateral extent cannot possibly enter into the definition of a facies; the former varies from less than 1 mm. to thousands of meters, while the latter may vary from enormous areal extent (the abyssal red clays of the Pacific Ocean occupy an area greater than that of North America) to an area of a few square meters occupied by a shell bank.

Nalivkin proposes a hierarchical classification of facies akin to that used in biology. Thus the broadest category is the Province (continent, ocean, geosyncline); the next category is the environment (delta, desert); the narrowest category is the basin of deposition (lake, lagoon). The line of inference which a program of geologic research produces, would begin with a layer of argillaceous shales which carry graptolites, proceed to the specification of a graptolite shale deposit, thence to the inference of a saline aqueous environment of deposition, and finally to the inference of a marine environment. This scheme illustrates a point which Nalivkin stresses at great length; the study of a facies is the study of total paleo-environment; it is not a branch of lithology.

The classification of marine environments, and the basins of deposition which each environment includes is as follows:

[1] This book is currently being translated under the auspices of the AGI Translation Center and will be published during the second half of 1959.

Open cratonic shelf: Level shore, rugged shore, drowned valleys, banks (flooded topographic highs), islands glacial-marine deposits, volcanic-marine deposits, pseudo-abyssal deposits.

Shelf with barrier: Gulf, bay, blocked strait, mangroves, mud basins, stagnant (saline) basins.

Lagoon: Lagoons in general, lagoon connected with coastal lake, "coastal playas", peat lagoon with coastal lake, sapropel lagoon with coastal lake, ferro-silicate lagoon with coastal lake, sand bar.

The continental sea, the interior sea, the archipelago, the reef region, and the bathyal and abyssal zones are environments which are not divided into depositional basin types.

The sediments laid down in various marine conditions are divided into fragmental-terrigenous (conglomerates, breccias, sandstones, siltstones, clays, oozes); organic sediments (carbonates, silicates, hydrocarbons; volcanic deposits (tuffs, breccias, ash, bentonites); chemical sediments (carbonates, iron and manganese ores, glauconites and phosphorites, bauxite); pseudo-abyssal sediments (foraminifera, pteropod and radiolaria oozes); mixed deposits (glacial-marine, volcanic-marine, submarine slumping).

A distinction between field data and the total paleo-environment constitutes the basis of Nalivkin's methodology. Nalivkin includes the following factors in the field data category: shape, size and sorting of grains; the mineralogy of the rock (a further clue to the mode of transportation); the color of the rock; the layering (particular attention should be paid to the properties of the surface of deposition); the depositional rhythm (a consideration of especial interest in the case of layers with irregular geometry); thickness (it should be borne in mind that total thickness may exceed average depth of water); inclusions; structure and texture (frequently important for the conditions of limestone deposition, and secondary in the case of sandstone deposition); the fossil assemblage (may be more important than the chemical precipitates in organic deposits); the composition of the (fossil) faunal population (frequently a clue to the environmental chemistry); composition of the (fossil) floral population (frequently a basis for the choice between an inferred mangrove and swamp environment); the dominant fossil forms as indicators of the paleo-environment (coral reefs, for example, indicate shallow warm marine waters); the relationships among the various fossil forms may serve as a clue to the conditions of burial (the occurrence of planktonic and benthonic forms together in considerable abundance, may indicate a relatively stagnant lagoon).

Nalivkin distinguishes three possible histories for a "normal" sedimentational cycle which begins with the deposition of coarse sands which is overlain by silt, and the latter, in turn, overlain by clay. The first history may be one of continuous deposition; the upward transitions between the granularometric types is entirely gradual in this case. More frequently, however, the deposition of the coarse sand will cease, a period of deposition of minor amounts of clay and more significant amounts of organic remains will be initiated, and an intensive deposition of silt will commence at the close of this period. The deposition of silt will in turn become negligible, a layer of miscellaneous remains will be deposited again, and (finally) a relatively intensive deposition of clay will commence.

The third history consists of the onset of strong action by bottom currents - and the accompanying erosion - after the intensive deposition of coarse sand has ended, the beginning of intensive clay deposition after the strong currents have ceased to act, the onset of a second period of strong bottom current action, and the onset of intensive clay deposition on the surface of submarine erosion which these currents carve.

The diagnosis of the total paleo-environment is carried out mainly on the basis of the fossil assemblage in the case of marine environments. The basis of the distinction between fluvial and lacustrine environments however, is made on the basis of lithologic evidence; lacustrine environments will almost inevitably be distinguished by a predominance of fine-grained rocks.

Strakhov, N. M., Brodskaya, N. G., Knyaseva, L. M., Razzhivina, A. N., Rateev, M. A., Sapozhnikiv, D. G., and E. S. Shishova., FORMATION OF SEDIMENTS IN RECENT BASINS: A symposium, Moscow 1954. 791 pp. A review by George V. Chilingar, University of Southern California.[1]

The Caspian Sea (77,000 km^3 of water) is surrounded by a more or less arid region. The aridity, however, is more pronounced on the eastern side. After separation from the main ocean (by way of the Black Sea), this relict sea has received considerable amount of salts from the entering streams. Some 328.6 to 336.5 km^3 of water with 7.93×10^7 tons of dissolved salts are added annually. The evaporation has also been appreciable, because now its surface is below sea level and it is still sinking. The explanation for the low salinity of the Caspian Sea (1.2-1.3%), therefore, lies in salt removal through the Gulf of Karabugaz which has salinity of 16.3 to 28.9%. Because of the excessive evaporation, a strong current is constantly flowing into this gulf from the Caspian Sea, bringing in about 350,000 tons of salt yearly (Shvetsov, 1948, p. 328).

The Caspian Sea currents are shown on Figure 1, and the surface salinity in 0/00 is presented in Figure 2.

FIGURE 1. Caspian Sea currents (after A. A. Mikhalevskiy, in Strakhov, 1954, p. 141).

FIGURE 2. Distribution of surface salinity (in 0/00) in Caspian Sea during February-March of 1934 (after Bruevich, in Strakhov, 1954, p. 141).

The difference in the ratios of ions in the waters of Caspian Sea as compared to those of the ocean, enabled Bruevich (in Alekin, 1953, p. 269) to calculate the approximate age of Caspian Sea. If the total amount of Cl^- and SO_4^{--} ions in the Caspian Sea water is equal to $\underline{a}$ and $\underline{b}$ tons and if the yearly amount brought by the rivers is $\underline{a}'$ and $\underline{b}'$ tons, respectively, then $\underline{n}$ years ago the Cl^- and SO_4^{--} contents of the water were by na' and nb' tons less than they are today. The Cl^-/SO_4^{--} ratio of the Caspian Sea water $\underline{n}$ years ago was equal to that of the ocean, namely 7,186. Thus the age of the Caspian Sea $\underline{n}$ (after its separation from the parent body) can be calculated from the formula

$$\frac{a - na'}{b - nb'} = 7,186$$

On using the above formula and correcting for the amount of deposited salts, Bruevich estimates the age of the isolation of the Caspian Sea at 10,600 years. On the other hand, on using Cl^--Mg^{++} and Cl^--Ca^{++} ions $\underline{n}$ is equal to 13,700 years. (Comment by Editor: Obviously there is faulty reasoning in assuming constant rated of salt input; the figures are interesting, but not definite. - R.W.F.).

[1] Other papers cited in this review are listed under references.

The drainage basin of the Caspian Sea is shown in Figure 3.

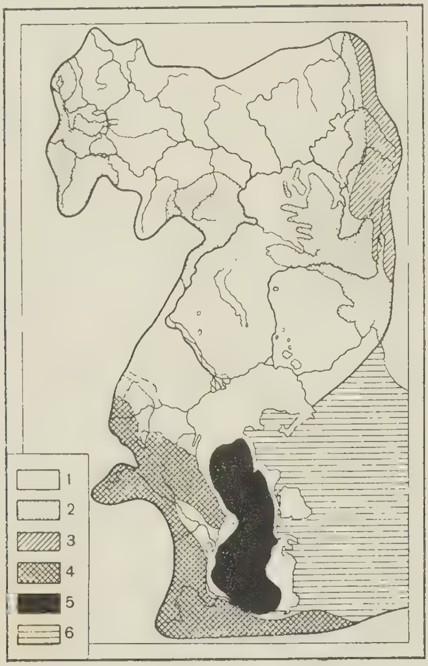

FIGURE 3. Drainage basin of Caspian Sea. (after Strakhov, 1954, p. 139). (1) 0-200 m elevation; (2) 200-500 m el.; (3) 500-1000 m el.; (4) above 1000 m el.; (5) sea depths greater than 100 m; and (6) additional area of eolian supply of Caspian Sea.

Chemistry of Caspian Sea. -- The ionic composition (in 0/00) of the Caspian Sea water is as follows: Na^+ -- 3.1698, K^+ -- 0.1043, Mg^{++} -- 0.3636, Ca^{++} -- 0.7309, Cl^- -- 5,407, Br^- -- 0.0068. SO_4^{--} -- 3.0125, and CO_3^{--} HCO_3^- -- 0.1026 (Musina, in Alekin, 1953, p. 269). The variation in the chemical composition, temperature, and pH with depth is presented in Table I.

On the basis of chemical characteristics, Bruevich (in Alekin, 1953, p. 272) divided the Caspian Sea into two vertical zones: (1) zone impoverished in biogenous elements (from surface to a depth of 100 m), and (2) zone enriched in biogenous elements $>$ 100 m). The upper zone, and especially the layer with intense photosynthesis (above 25-50 m), is characterized by the low NO_3^-, P, and Si contents. The lower zone, on the other hand, is enriched in P and Si contents. The O_2 content decreases with depth in the lower zone, and in the Southern Caspian completely disappears at the bottom. Some H_2S is present here in low concentration (up to 0.29 ml/l).

The NaCl, $MgSO_4$, $MgCl_2 + MgBr_2$, $CaCO_3$, KCl, $CaSO_4$ contents (in %) of the Caspian sea as compared to those of the ocean waters are 62.15, 23.58, 4.54, 1.24, 1.21, 6.92; and 78.32, 6.40, 9.44, 0.21, 1.69, 3.94, respectively. Thus the Caspian Sea water is enriched in magnesium and calcium sulphates and has lower NaCl content as compared to that of the Ocean. High alkalinity (3.16-3.6 mg-equivalents) and high pH (8.3-8.4) are also characteristic of the Caspian Sea water.

The variation in composition and properties of the interstitial solutions of Caspian Sea sediments with depth below the depositional interface have been studied by S. V. Bruevich and E. G. Vinogradova (1947, in Chilingar, 1958, p. 213-216).

Caspian Sea Sediments. -- Sediments of the Caspian Sea are similar to those of the Black Sea (Chilingar, 1956, p. 2767) and contain abundant calcareous material present either as a fine-grained pelitomorphic (muddy) sediment or as coquina. The Caspian Sea sediments are divided into the following types (Strakhov, 1954, p. 149); (1) sands, (2) oölitic sands, (3) coquina, (4) coarse-silty muds, (5) fine-silty muds, (6) calcareous-clayey muds with low $CaCO_3$ content ($<$ 30%), and (7) calcarous-clayey muds (Figure 4).

The grain size distribution of the sands depends largely on the shell material content, which varies from a few per cent to 60-70% of the sediment. The average diameter of the sands rich in shell material is equal to 0.64 mm, whereas the sands containing small amounts of shell material have an average diameter of 0.20 mm. The latter sands are also better sorted. The mineral grains are usually well rounded (specially in the eastern part of the Northern Caspian).

The shell fragments in sands include those of Cardium edule, Didacna species Dreissensia polymorpha, and others. According to Bruevich (in Strakhov, 1954, p. 151), the chemical composition of sand with coquina in the Northern Caspian is as follows: insoluble residue in 10% HCl --

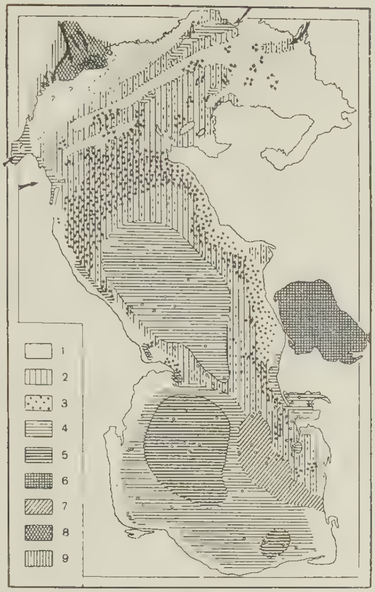

FIGURE 4. Caspian Sea sediments (after M. V. Klenova, V. P. Baturin, and A. F. Nosov, in Strakhov, 1954, p. 150). (1) sands; (2) coarse-silty muds; (3) coquina; (4) fine-silty muds; (5) clayey-calcareous muds; (6) supposedly fine-silty deposits; (7) calcareous-clayey muds; (8) deltaic deposits of Volga River; and (9) near-delta bay deposits.

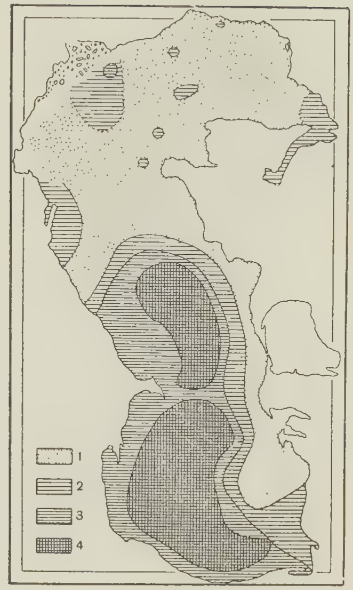

FIGURE 5. Manganese content in Caspian Sea sediments (after A. S. Pakhomova, 1948, in Strakhov, 1954, p. 171). (1) $<$0.03%; (2) 0.03-0.05%; (3) 0.05-0.1%; and (4) above 0.1%.

48.5%; $CaCO_3$ -- 43.3%; and Fe and Mn contents in 10% HCl extract -- 0.22% and 0.021%, respectively. Pakhomova (in Strakhov, 1954, p. 151) reports the average Mn content in Caspian Sea sands at 0.022%, whereas the average amount of P is 0.032% (Budyanskaya, 1948). (Figures 5 and 6).

The major portion of the oölitic sand is composed of oölites (80-90%), with the remains of the mollusks forming the remainder of this sand. The regular terrigenous material is practically absent. The oölites are of gray, dark gray, yellowish, and orange color, and range from 0.1 to 0.2 mm in size. They have either spheroidal, ellipsoidal, or slightly compressed shapes, with a few laminae around the shell fragments. Many rounded shell fragments resemble oölites.

The other variety of oölitic sands is characterized by the presence of gray calcareous-clayey cement surrounding oölites. The nuclei of the oölites consist of pieces of shells, small gastropods, quartz, hornblende, mica, or calcite.

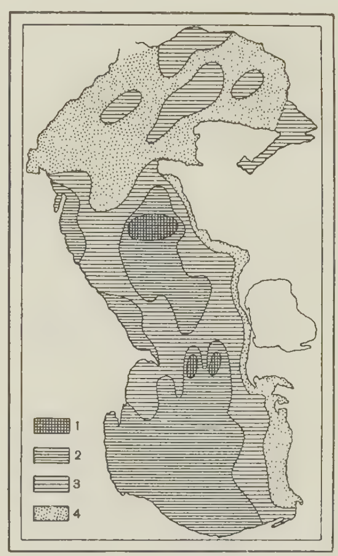

FIGURE 6. Distribution of phosphorus in the Caspian Sea sediments (after M. L. Budyanskaya, 1948, in Strakhov, 1954, p. 171). (1) above 0.10%; (2) 0.10-0.07%; (3) 0.07-0.04%; and (4) $<$ 0.04%.

The $CaCO_3$ content of oölitic sands is very high and reaches 85.72-95.8%. The grain size distribution of oölitic sands

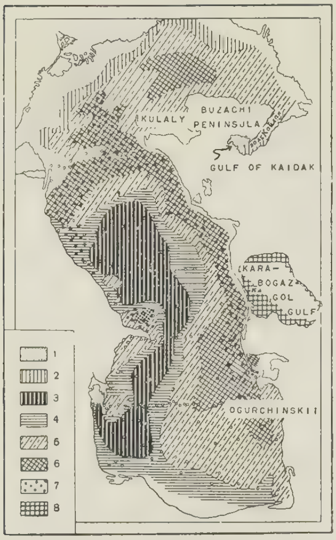

FIGURE 7. Distribution of carbonate deposits in Caspian Sea (after V. P. Baturin, A. F. Nosov, M. V. Klenova, and S. G. Sarkisyan, in Strakhov, 1954, p. 165). (1) less than 5%; (2) 5-10%; (3) 10-15%; (4) 15-20%; (5) 20-50%; (6) above 50% (up to 95%); (7) coquina; (8) chemical deposits of Kara-Bogaz-Gol.

varies considerably -- in some samples the median diameter is 0.11-0.4 mm, whereas in others it is 0.7-1.0 mm. The admixture of shell detritus results in higher median particle size.

The composition of other Caspian Sea sediments are presented in Tables II, III, IV, **V**, and VI.

Figure 7 shows the distribution of the carbonate deposits, which comprise (1) oölites, (2) carbonate crusts, (3) coquina, and (4) pelitomorphic carbonate.

The pelitomorphic $CaCO_3$ is believed to result either from direct precipitation out of sea water on evaporation, or represents very fine suspended carbonate brought by the rivers, and it is not know which kind predominates. The chemical and thermal analyses often reveal the presence of $MgCO_3$ (2.0-6.86%), which is reported to be present as dolomite. Part of this dolomite is brought in suspension by the rivers, and the other part seems to be of diagenetic origin (Strakhov, 1954, p. 163).

Bruevich (1949, in Strakhov, 1954, p. 164) determined the annual amount of deposition of marine authigenic carbonate in various parts of Caspian Sea. It ranges from 100-1140 g/m^2 in shallow parts of the sea and bays to 25 g/m^2 at depth of 900 m (average of 82 g/m^2 $CaCO_3$ annually).

The distribution of organic carbon in the Caspian Sea sediments is presented in Table VIII.

TABLE I. Variation in chemical composition, temperature, and pH of Caspian Sea water with depth (after S. V. Bruevich, in Alekin, 1953, p. 272)

Depth	Cl	O_2	H_2S	NO_2^-	NO_3^-	P	Si	t^o	pH
m	0/00	ml/l	ml/l	mg N/l	mg N/l	mg P/l	mg Si/l		
0	5.38	5.35	0	0	0	0.3	226	24.18	8.44
10	--	5.39	0	0	0	0.1	212	--	8.45
25	--	5.54	0	0	0	0.1	245	--	8.42
50	5.32	5.15	0	0.1	0	2	331	9.58	8.22
100	5.34	4.36	0	0.1	83	11	547	7.11	8.09
200	5.37	3.31	0	0	161	24	749	6.14	8.00
400	5.40	2.05	0	0	161	41	1315	5.90	7.90
600	5.42	0.42	0	0	64	49	2116	5.93	7.81
800	5.40	0.02	0.18	0	0	--	--	5.96	7.74
900	--	0.04	0.29	0	0	65	2742	--	--

TABLE II. Chemical composition of coquina (in %) (after S. V. Bruevich, in Strakhov, 1954, p. 153

Location	Insoluble residue in 10% HCl	$CaCO_3$ from CO_2	In 10% HCl extract		
			Fe	Mn	P
Northern Caspian (4 samples)	3.9	81.8	0.26	0.007	0.009
Middle Caspian (2 samples)	6.8	91.1	0.26	0.017	0.022
Apsheron threshold (4 samples)	8.9	83.6	0.20	0.011	0.025

TABLE III. Average grain size analysis of coarse-silty muds of Caspian Sea (in %), after Strakhov, 1954, p. 154
(values in parentheses show the amounts of shell material)

Sediment	Weight per cent of size groups, diameter in mm					M_d, mm	S
	>1.0	1.0-0.1	0.1-0.05	0.05-0.01	<0.01		
Coarse-silty muds with large amount of coquina	(16.8)	27.9	58.5	5.6	8.0	0.080	1.41
	(23.2)	26.8	40.0	9.5	23.7	0.061	1.26
Coarse-silty muds with small amounts of coquina	(2.6)	7.9	71.3	11.8	9.0	0.065	2.57
	(0.8)	6.0	53.2	22.9	17.8	0.057	2.0

TABLE IV. Average grain size analysis of fine-silty muds of Caspian Sea, after Strakhov, 1954, p. 155

Sediment	Weight per cent of size groups, diameter in mm					M_d, mm	S_o
	>1.0	1.0-0.1	0.1-0.05	0.05-0.01	<0.01		
Fine-silty muds with coquina (near-shore)	(11.3)	5.77	21.58	42.6	31.0	0.027	2.7
Fine-silty muds devoid of coquina (deep-water)	0	trace	27.3	31.7	45.0	0.014	4.5

TABLE V. Chemical composition of clayey-calcareous muds of Caspian Sea (in %), after S. V. Bruevich and E. G. Vinogradova, 1949, in Strakhov, 1954, p. 157

Sediment	Insoluble residue in 10% HCl	$CaCO_3$ from CO_2 determination	In 10% HCl extract		
			Fe	Mn	P
Clayey-calcareous mud from eastern shelf of Southern Caspian	26.6	56.6	0.90	0.031	0.040
Same as above	17.7	71.8	0.68	0.020	0.027

TABLE VI. Size distribution of slightly calcareous clayey muds of Southern Caspian (in %), after M. V. Klenova, 1946, in Strakhov, 1954, p. 158

Diameter in mm	Weight per cent of size groups					
	Station 3 (789 m depth)	St. 5 (695 m depth)	St. 19 (395 m depth)	St. 19 (960 m depth)	St. 20 (960 m depth)	St. 31 (890 m depth)
> 1.0	--	--	trace	--	--	--
1.0-0.1	trace	trace	trace	trace	trace	trace
0.1-0.05	23.6	20.2	24.4	20.9	25.0	27.3
0.05-0.01	26.1	23.7	26.6	27.6	20.9	18.9
> 0.01	50.3	56.1	49.0	51.5	54.1	53.8

TABLE VII. Chemical composition of slightly calcareous ($CaCO_3$ < 30%) clayey mud (in %), after S. V. Bruevich and E. G. Vinogradova, 1949, in Strakhov, 1954, p. 158

Locality	Insoluble residue in 10% HCl	$CaCO_3$ from CO_2 determination	In 10% HCl extract		
			Fe	Mn	P
Southern Caspian, depth of 900 and 960 m (2 samples)	64.2	20.1	2.70	0.103	0.060

TABLE VIII. Distribution of organic carbon in Caspian Sea sediments (in %, average values), after M. V. Klenova, in Strakhov, 1954, p. 174

Locality	Sands	Coarse-silty muds	Fine-silty muds	Pelites
Northern Caspian	0.26	0.75	1.11	1.2
Southern Caspian, deep-water sediments	--	--	1.50 (0.90-2.25)	--
Apsheron Elevation	--	0.31 (0.17-0.38)	--	--

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Notes on international scientific meetings

CONFERENCE ON THE PROBLEMS OF THE ORIGIN OF OIL
Moscow, October 1958

A recent conference devoted to discussions on the problems of the origin of oils was held in Moscow from October 20 to October 25, 1958, under the auspices of the Academy of Sciences of the USSR Minister of Geology and Mineral Conversation of the USSR.

The participants in the program and the papers presented were as follows:

1. Introductory Address of Vice President of the Academy of Sciences of the USSR, Academician A. V. Topchiev, on the tasks of the conference.

2. Report by President of the Steering Committee and Corresponding Member of the Academy of Sciences of the USSR, M. F. Mirchink, "The present status of the theory of the origin of oil and the tasks of further investigation." (translated in full in this issue, pp. 73-101.)

3. Report by V. B. Porfirev, Academician of the Ukrainian Academy of Sciences, on "The nature of oil."

4. Report of N. A. Kudryavtsev, Doctor of Geologic-Mineralogical Sciences, "Inorganic genesis of oil."

5. B. V. Veber, Doctor of Geological-Mineralogical Sciences, "The formation of bitumens in quaternary marine sediments in connection with the problem of the origin of oil."

6. V. A. Uspensky, Doctoral Candidate of Chemical Sciences, "The stages in the formation of oil and their place in the system of carbon geochemical cycles."

7. V. A. Sokolov, Doctor of Chemical Sciences, "Chemical processes of the formation of oil and primary migration."

8. A. A. Trofimuk, Academician, "About the hypothesis of the inorganic synthesis of oil."

9. A. A. Bakirov, Doctor of Geological-Mineralogical Sciences, "The most significant criteria in the accumulation of oil and gas in the earth's crust, which confirm the organic origin of oil."

10. Sh. F. Mekhtiev, Academician of the Azerbaidjan Academy of Sciences, "Oil-producing formations in the Azerbaidjan oil-bearing province."

11. I. O. Brod, Doctor of Geological-Mineralogical Sciences, "The principal results of the study of dissipated organic substances in the Mesozoic and Cenozoic rocks in the eastern Caucasian foothills."

12. D. V. Zhabrev, Candidate of Geological-Mineralogical Sciences, "Characteristics of oil producing formations, on the basis of materials from investigations in Azerbaidjan, Daghestan, and central areas of the Russian platform."

13. M. F. Dvali, Doctor of Geological-Mineralogical Sciences, and N. A. Eremenko, Candidate of Geological-Mineralogical Sciences, "Outline of program of research in the problem of the origin of oil and the formation of its deposits."

There was a discussion of the reports and presentation of information on material of personal investigation. The conference voted its approval of the proposed program of research into the origin and accumulation of oil as outlined by Dvali and Eremenko (see 13 above).

An Interinstitutional committee was elected for the problem, "The origin of oil and gas and formation of oil and gas deposits."

COLLOQUIUM ON THE TOPOGRAPHY AND GEOLOGY OF THE DEEP SEA FLOOR

Nice, May 1958

by Robert S. Deitz

ABSTRACT

This communication describes a colloquium of this title held at Nice in May 1958 under the sponsorship of the Centre National de la Recherche Scientifique, to coincide with the opening of Professor J. Bourcart's new marine laboratory at Villefranche, which will be devoted to marine geological investigations of the Mediterranean. This is an excellent facility and the first marine station dedicated to marine geological investigations in Europe. An over-all impression received by the water is that the science of marine geology in Europe still lags far behind its status in the U.S.A. The remainder of this communication consists mainly of brief summaries of a selected group of the papers presented.

A Colloquium on the Topography and Geology of the Deep Sea Floor (La Topographie et la Geologie des Profondeurs Oceaniques) was convened at Nice and Villefranche, France, from May 5 through 12, 1958. It was the 83rd colloquium of a series sponsored by the French national agency for scientific research -- the Centre National de la Recherch Scientifique (CNRS). Invited non-French participants came from Norway, Sweden, England, the Netherlands, Italy, and Spain. Overseas participants came only from the United States and were H. W. Menard, Scripps Instn. Ocean, B. Heezen, Lamont Geol. Obs.; K. O. Emery, U.S.C.; and the writer.

The principal reason for the convening of this meeting was the official opening at Villefranche of a new marine laboratory to be devoted entirely to marine geology. The dedication of this laboratory took place on the last afternoon of the Colloquium, with the ceremonies being broadcast throughout France. This new research facility is under the direction of Professor Jacques Bourcart (University of Paris) and will be an extension of his small Laboratoire de las Geologie Sous-Marine at the Sorbonne. The establishment of this facility is an important milestone for marine geology since it is the first marine station in Europe to be devoted to the subject.

There are presently numerous marine biological stations and a few devoted to physical-chemical oceanography, but it has not been the custom in Europe to develop composite laboratories which are concerned with all aspects of the marine sciences as in the United States. Thus, until this time marine geology has been conducted entirely within university departments, with little direct access to the sea. Professor Bourcart now plans to spend six months of each year at Villefranche and the remainder in Paris. It is expected that most of his staff and research program will be transferred to Villefranche.

The laboratory is located in a newly rehabilitated historic building adjacent to the University of Paris' Zoological Station at Villefranche. Being an historical monument, it was necessary for the architects to preserve the external facade and to remodel the building without compromising its classical architectural form. The piece de resistance is the corkscrew chimney. This is all to the good, although doubtless an expensive procedure and one which has delayed the reconstruction. The interior of the laboratory is essentially one great room, cut up into several bays, with a high vaulted Gothic ceiling. There is also a second floor, but no authority has been obtained yet for its reconstruction and use. Both this building and the zoological Station were erected about five centuries ago by the King of Sardinia to be used as a base for his galleons. The lower floor of the Zoological Station is a large dungeon where the galley slaves were kept. Rows of cement blocks to which they were chained are still present, extending in long lines over the floor.

One day of the meeting was spent at Monaco where the Museum of Oceanography, newly under the direction of Cmdt. J. Y. Cousteau, was visited in the morning and the International Hydrographic Bureau

[1] Office of Naval Research, U.S.N.

in the afternoon. During the past year Cousteau has reorganized the Museum, both administratively and as a popular attraction. It will doubtless become a first-rate oceanographic research facility within the next few years. By revamping the aquarium he has already been able to double the income to about two-thirds of a million dollars per annum. In addition to a wide variety of spectacular fishes, he has introduced tanks for marine mammals (California sea lions and porpoises).

The afternoon session at the International Hydrographic Bureau was concerned with the problem of nomenclature of sea floor features and their international standardization. The term "continental borderland," as applied to the special type of continental shelf off southern California, was subjected to a good deal of criticism.

Another day of the Colloquium was devoted to a cruise at sea aboard Cousteau's research vessel, Calypso, a converted YMS, and the new research ship of the Oceanographic Museum of Monaco the Vinagretta Singer. Although the Calypso is personally owned by Cousteau and extensively used by his research group at Marseille, it is also leased for extended periods by the French Government for use as a national oceanographic facility. She has presently been leased for the entire eighteen months of the IGY for extended hydrographic cruises in the Atlantic Ocean under the leadership of Professor H. Lacombe. The Calypso is excellently equipped for oceanographic work, especially emphasizing scuba techniques. One new apparatus is a rotating crane located on the port side of the fantail for picking up and launching heavy pieces of equipment. This was installed especially for handling Cousteau's new two-man diving submersible Le Tortu. Unfortunately, the first full-scale mock-up of this small submarine-like craft was lost recently during deep submergence tests designed to determine its ability to withstand pressures at 400 meters, due to a parting of a cable when attempting to retrieve the device from the sea surface. Thus, the program of development of this radically new submersible has been delayed for at least a year. Another novel installation on the Calypso is the placement of the Edo echo sounder transducer at the leading edge of the bow to avoid blocking of the sound pulse by bubbles. The device works excellently and is said to be simpler and more effective than any type of bubble shield. The V. Singer is a new ship just built for the Oceanographic Museum through funds granted by the Singer Foundation. It is a small ship, devised only for coastal work, and will be mainly concerned with making the collections to sustain the aquarium.

Following CNRS policy, which presumably hopes to bolster the declining prestige of the French language in international scientific circles, the Colloquium was conducted as far as possible in French. Inevitably English was used by several of the speakers, but summaries were given in French. All the papers of the Colloquium will be published in French in about a year as a special CNRS publication.

An over-all impression of the Colloquium by the writer, is that the status of the science of marine geology in Europe and especially in France is far behind that in the United States. The papers by Emery, Heezen, and Menard were particularly good, being based upon great amounts of recently collected data. The French have not as yet undertaken any studies of the Atlantic Ocean beyond coastal problems and have little data to go on in the Mediterranean. Most of the papers concerning the Mediterranean were extrapolations of land geology. However, Bourcart has almost completed a new bathymetric chart of the western Mediterranean that appears to be based on a sufficient amount of data to provide considerable topographic detail. This should help to place discussions on this part of the Mediterranean basin on firmer ground. Doubtless, the new laboratory will do much to upgrade marine geology in France. The French have led the world in manned invasion of the shallow seas throubh scuba diving as well as of the deep sea through bells and the bathyscaph FNRS-3. They are also second to no nation in the field of marine zoology, so that it is fitting that they play a more important part in marine geology.

In the remainder of this communication summaries of a selected group of the communications are alphabetically presented. The additional papers are finally listed by

title; summaries of these have not been given for the most part since they are concerned with local geographic problems.

Blanc, J. J., Peres, J. M., and J. Picard., Endoume Marine Station, Marseille, "Deep Corals and Quaternary Thanatocoenoses in the Mediterranean": This paper, read by Peres, considered the distribution of "yellow corals" (Dendrophyllia cornigera and D. ramea), which are bathylitteral forms found typically at a depth of about 200 meters and in the neighborhood of the shelf break, and of "white corals" (Madrepora oculata and Lophelia prolifera), which are epibathyal forms found typically at a depth of about 450 to 700 meters. An especially interesting aspect of the paper was that much of the data was collected from the French bathyscaph by Peres and Picard who have jointly made more than a dozen dives. The authors consider that these corals, as found presently in the Mediterranean, are relics of an extensive Quaternary population. During that time these forms prospered and had wider distribution than now because the Mediterranean then had a more vigroous circulation and a much higher organic production. Also, it was suggested that in the Quaternary the continental slopes were not so heavily invaded with mud as at the present.

Bourcart, J., University of Paris, "Morphology of the Pre-Continent from the Pyrenees to Sardinia": Professor Bourcart recapitulated investigations of the continental shelf and slope made over the past decade by himself and his students off the south of France. Through his efforts, the topography of this regions is now known in considerable detail due to special surveys made by various French Navy ships and by the Calypso. Most recently, the topography of the sea floor off the west coast of Corsica has been intensively developed by numerous sounding lines of the Calypso. For the most part, the paper concerned Bourcart's concept of the origin of the submarine canyons off the south of France the origin of which 20 have now been identified. Bourcart contends that they are river valleys which have been drowned by flexural warping of the continental margin or what he terms the "pre-continent." He feels that turbidity currents have played at most a very minor role in the development of the submarine canyons since these are cut into rock. He pointed out that the composite origin as espoused by Shepard cannot be accepted in the case of the Mediterranean, nor can any great regression of sea level account for them, since the depth of the Strait of Gibraltar sill is only 400 meters. Bourcart believes that the down-bending of the continental margin accompanied the development of the modern Mediterranean at the end of the Miocene. Thus, the canyons are chiefly mid-Miocene river valleys. He feels that the correlation between ancient (but not modern) river valleys and submarine canyons is good; e.g., the ancient mouth of the Rhone ties in with the large submarine canyon, although no canyon is presently developed off that river. The down-warping of the continental margin was said to be greatest off the anticlinal regions of the coast which corresponds with coastal convexities and which have been at a minimum along synclinal regions corresponding to concave parts of the coast. As proof of the Miocene age of canyon cutting, Bourcart cited the filling up of some of the canyons with alleged continental Pliocene gravels.

From discussions following the paper, it appeared that Bourcart's thesis has little acceptance outside of the French school. A principal objection was that his hypothesis requires at first a marginal uparching of the coast. This mountain arch must then have been dissected by antecedent rivers. Then this arch must be flexed below sea level. Thus, the talwegs of the submarine canyons should be convex upward, but they are, in fact, concave.

Emery, K. O., University of Southern California, "Nature and Origin of the Continental Borderland off Southern California": This paper was a summary discussion of the unique continental borderland off southern California which differs from normal continental terraces in that it is composed of numerous deep basins and banks. (Emery speaks with great authority upon this region since he had studied it intensively for twenty years and is now completing a book about it). The basement rocks here are the Franciscan metasediments which were deposited in a Mesozoic geosyncline and then folded and isostatically elevated. The region was then peneplaned, and a normal shelf

existed off California until Miocene times when extensive block faulting and volcanism took place. The banks have been non-depositional since Upper Miocene, as shown by phosphorite deposits containing Miocene foraminifera; all the sedimentation has taken place in the basin.

The basins nearest the shoreline are much more rapidly filled with sediment than those further offshore, and some, in fact, have been completely filled, e.g., the Los Angeles basin. Much sediment is carried along the coast from north to south. Large amounts are trapped in the submarine canyons and subsequently carried out into the near-short basins by turbidity currents. A study of the apron-like deposits at the mouth of the submarine canyons shows that these are graded turbidity current deposits. They have a large sand-to-shale ratio as compared to the largely pelagically deposited basin sediments in the offshore basins. Various aspects of the continental borderland (vz., the height of the bank tops, the depths of the basins, the depths of the basin sills, and the depth of the shelf break) show that the borderland has undergone a warping to the southwest. Warping extending back to the Tertiary is indicated by the first three properties mentioned, but the southwestward increasing depth of the shelf shows continued warping in late Pleistocene and Recent times.

Cousteau, J. Y., Director, Oceanographic Museum, Monaco, "Some Secondary Techiniques in Oceanography": Cmdt. Cousteau discussed new oceanographic techniques developed by him and his colleagues, many of them in collaboration with Professor H. Edgerton of M.I.T., mostly for use on the Calypso.

One new development concerned the use of braided nylon rope for anchoring an oceanographic ship to maintain a fixed position in the deep sea. Nylon rope has the advantage of having almost no weight in water, so that its strength is not largely expended in supporting its own weight. Only very light tackle rather than heavy wrenches is required for its handling aboard ship. However, the use of nylon imposes serious difficulties and special handling as it is easily abraded and undergoes an elastic elongation of 20% before breaking; therefore, some of the difficulties are like those of trying to anchor with a rubber band. In addition it cannot be stored on a spool under tension, so that the hauling-in winch must be separate from the storage spool.

The first experiment with nylon rope was undertaken in 1955 in the Deep of Matapan off Greece at a depth of 4,200 meters with a 6 mm rope and a 50 kg anchor. The free fall of the anchor to the bottom required 35 minutes, and one of the small boats of the Calypso was anchored for 24 hours. In July 1956, in the Romanche Trench, the Calypso itself was anchored at a depth of 7,500 meters with a 12 mm nylon rope 8,300 meters long. Under the tension involved this rope elongated 6% or to a total length of around 8,800 meters. Thus anchored, the Calypso remained three days and two nights in a force three sea against winds of 15 knots and a north-setting current of as much as 1.5 knots. Owing to the essentially zero weight of the nylon, there was no catenary in the cable. This was a world record for deep anchoring, far exceeding the depth of 5,500 meters in which the Meteor, for example, anchored with a steel cable many years ago.

Dredging is another use for nylon rope aboard the Calypso. A 6 mm rope with a rupturing strength of only 650 kg has been so utilized by Peres. It was successfully used under conditions where a two-ton breaking-strength wire rope would probably have parted, since its elastic properties help to cushion any sudden shock. Once again, special gear and handling methods must be used and the dredging must be done skillfully rather than with brute force. One indispensable precaution is to reinforce the end of the cable with a length of wire rope to avoid bottom abrasion of the nylon.

For use aboard the Calypso, Edgerton has developed a sonic near-bottom indicator which is nick-named the "Tik-Tik." This is essentially a small self-contained echo sounder which can be attached to a bottom camera or to other oceanographic devices when their exact position with respect to the bottom needs to be known. Sound pulses are simultaneously sent directly to the ship and bounced off the bottom. These are detected by the Edo's

sound receiver. The delay in arrival of the sound pulse bounded off the bottom, as compared with that directly transmitted, is presented visually on an oscilloscope. In this manner it is possible to position a freely suspended camera a couple of meters off the bottom with a precision of about half a meter.

Cousteau discussed at considerable length underwater photography, on which he is perhaps the world's foremost authority. Types of photography considered included: (1) photography by the scuba swimmer, (2) photography from nacelles--that is, from bells, small submarines or bathyscaphs, (3) photography in midwater, and (4) photography of the bottom. Since 1953 more than 30,000 photographs have been taken in the Mediterranean. In the Atlantic, it has been possible to obtain three photographs at a depth of 7,200 meters at the bottom of the Romanche Trench--a record depth for bottom photography. Through midwater photography, he has revealed the "sea snow" now well known to bathyscaph divers at mid-depths. Photos also show the absence of any great visible biological accumulation in the deep scattering layer and the existence of a biological concentration at depths from 700 to 100 meters.

Television is another technique which has been highly developed by Cousteau and his associates, but the details of this are too involved to consider here.

Dietz, R. S., U. S. Office of Naval Research, Lond, "Asteroidal Impact Origin of Ocean Basins: A Hypothesis": This communication pointed out that the problem of the origin of the ocean basins essentially required explanation of the discontinuous development of the earth's exterior sialic layer. The present hypothesis suggests that the sial may have been fragmented early in earth history by the impact of asteroids. In one way, then this is the reverse of G. H. Darwin's catastrophic lunar extract on theory. In another way, however, it is the reverse of Barrell's volcanic foundering hypothesis since this author referred to the lunar maria and compared them with ocean basins. Contra Barrell, Dietz pointed out that it is now quite evident that lunar craters were formed by meteorite impact and the maria by asteroid impact; and that if the moon has been so struck, so must also have been the earth. It is well known that the moon is almost entirely free from exogenic processes (water erosion, weathering, etc.), but it is not so commonly appreciated that the moon probably is also almost free from hypogenic processes (tectonism, volcanism, etc.) because of its geophysically small size. Thus, the moon preserves in pristine form early events in its history while the earth does not. Dietz therefore supposes that the present geographic form and distribution of ocean basins probably have no relation to these ancient asteroid impacts which may have fragmented the earth's crust. There is some evidence to suggest that all large meteorites as well as the asteroids are the broken-up remains of a former planet that existed in the orbit between Mars and Jupiter. Cosmogenic ages of meteorites suggest that this breakup took place about 1.3 billion years ago. It is likely that many asteroids were then swept up quickly by the earth and the moon; the asteroids, which have remained to the present, have survived because they are in noncollision orbits.

Gaskell, T., British Petroleum Co., Ltd., "The Seismic Structure of the Great Oceanic Depths": Gaskell compared the American two-ship system for making deep sea seismic refraction stations with the British one-ship technique used by himself and Swallow on the Challenger II, and subsequently by M. N. Hill from the Discovery. The British system has only a short range, so that the Mohorovicic discontinuity is not generally revealed by first arrival waves. However, more detailed information is obtained on the intermediate depth layer (termed "Layer 2" by Gaskell) because of the use of a series of sonobuoy receiving points at each station. The most striking result so far is the universal presence of a deep layer above the "Moho" with a velocity of 6.7 ($\pm$ 0.28) km/sec. Such a velocity cannot be explained by any acidic igneous or sedimentary rock, excepting certain rare types of limestone. Aside from the geochemical unlikelihood that this layer is limestone, it propagates sound waves in order of magnitude too well to be so explained. Because of layering, fracturing, etc., and great horizontal variations in transmission

velocity, limestone rapidly attenuated seismic waves; hence, this layer must certainly be a basic igneous rock.

Gaskell's main points concerned Layer 2 which lies above the 6.7 layer. It has a velocity varying from 4.3 to 6.3 km/sec and underlies the unconsolidated surface sediments. Through a study of shear waves, Gaskell believes that this layer is invariably present even though it is sometimes obscured by the first arrival of seisms from the 6.7 layer. He thinks that Layer 2 is actually one of two types of rocks, viz.: (1) effusive volcanic rock, when the velocity is less than 5.0 km/sec. This velocity has been principally observed near volcanic islands and seamounts and has been found to average about 2.6 km in thickness, and (2) metamorphosed or cemented sedimentary rock, when the velocity is 5.0 km/sec or more. Such rock is found principally in the flat-bottomed regions of the oceans and has an average thickness of about 1.0 km. In regard to consolidated rock, Gaskell referred extensively to the recent paper by Hamilton (Pac. Sci. Congress) with which he is in agreement.

Gaskell further discussed seismic stations inside the so-called "andesite line" where he considers that the bottom is semi-continental--even in the deep Philippine Sea. This seems to be at variance with the opinion of U. S. oceanographers. It was Gaskell's contention that the time is now ripe for deep sea drilling to test the various seismic concepts. (He has already stirred up in Britain considerable scientific and popular interest in such drilling, but suggests that "the Americans or the Russians should do it.") One project would be to drill at 14 km hole in a coral atoll to reach the Moho discontinuity. A hole of about 35 km would be needed to attain this layer if drilled on a continent. This would be twice as deep as any hole so far drilled, but in his view it is feasible. Drilling through the volcanic rock beneath the coral cap would be hard going, but dangers of hole-collapse, etc., would be minimized. He estimates that the cost for such a hole might be about $30 million. He does not seem to feel that the Moho layer would be isostatically too greatly depressed beneath a coral atoll. A second imaginative but much easier project would be to drill through Layer 2 in the deep ocean to reach the 6.7 layer. Gaskell feels that the technique of drilling from a barge which has been developed by a consortium of oil companies in California could be extrapolated to deep ocean use. Both these projects apparently have been endorsed by 1957 Toronto IUGG resolutions. He pointed out that an earth satellite was in space only three years after a 1954 IUGG Rome resolution supporting the project.

Glangeaud, L., University of Paris, "Tectonophysical Characteristics of the Western and Eastern Mediterranean": Glangeaud considers that the Mediterranean is neither a simatic-bottomed ocean (Atlantic or Pacific type) nor a sialic-bottomed sea (epicontinental type), but rather an intermediate type. (Seismic results in the Mediterranean thus far suggest that it is different from the Atlantic or Pacific. It has been impossible to reach the "Moho" as yet.) He believes that the underlying most of the Mediterranean there generally is an extensive thin "foot" of highly fractured and discontinuous sialic rock, which he calls a "precontinent" following Bourcart. Beneath the soft Recent sediments, he believes that the 6.7 km/sec simatic layer is only very locally exposed. Glangeaud has delved extensively into the paleogeography of the Mediterranean and concludes that its present form dates from only the Alpine orogeny at the end of the Oligocene. Prior to that, the Mediterranean had undergone a rather complicated history, with the sea being both open and closed at various times in the Mesozoic and Paleozoic. This history is related to continental movements of the European and African blocks.

Glangeaud believes that the Paleozoic Mediterranean (Paleothehys) must have had a simatic floor but that both Europe and Africa grew larger through the development of liminary mountain chains at the end of the Carboniferous (Hercynian folding). Thus, during the Upper Permian and Lower Triassic the Mediterranean was a land mass. In the Late Triassic and in the Jurassic, the Mediterranean sea disappeared owing to an extension between the Aftrican and European continental block. He terms this new sea "Mesotethys."

In the Oligocene the African and European blocks met again, causing the Alpine folding, but once again this was followed by subsidence in the Miocene. Therefore, the Mediterranean has had a very special history which separates it from the marginal regions of most continents and from the development of insular arcs.

Gougenheim, A., French Hydrographic Office, "The Characteristics of the Hydrographic Contribution to the Knowledge of Submarine Topography": Gougenheim, who was formerly Head of the Oceanographic Section and is now Director of the French Hydrographic Office, described the latter's surveying program. He pointed out that the mission of such an office is chiefly concerned with the safety of navigation and that this generally conflicts with scientific interest. For example, until very recently most of the surveys were only run out to the 200 meter isobath.

Guilcher, A., University of Paris, "Submarine Deposits on the Molene and Sein Shoals, Finistere": The Molene and Sein shoals are located off western Brittany where strong tidal currents exist. Because of this strong ebb and flow, on deposition of sand and gravel is possible and many dune-like sand deposits have been produced. These sand bodies include longitudinal strips, parabolic dunes, barchans, Z-shaped dunes, and giant ripples with Zostera meadows. The calcium carbonate detrital material is found mainly in the deeper areas and is composed mostly of Lithothamnion calcareum. The coarsest gravels are found principally below low water mark, and several types of deposit are distinguished. The coarse sands are generally poorly rounded. In this region a tide range of about seven meters exposes vast areas of sea floor, making it an ideal region in which to study shallow water deposition in a tidal regime.

Heesen, B. C., Lamont Geological Observatory, Columbia University, "Marine Geology and Continental Drift": Heezen pointed out that recent paleomagnetic and paleoclimatological studies have renewed interest in the hypothesis of continental drift. He believes that, although extremely new, the results of marine geological investigation have important bearing upon hypothesis. The topography and structure of the great depths place important limits on the distance and direction of any such displacements. A basic assumption of continental drift requires that the continents are light segments which float upon a universal substratum of uniform density. This has in fact now been verified through sea floor seismic refraction studies and through the precise interpretation of gravity anomalies over the sea. On the other hand, the work at the Lamont Geological Observatory has not verified the concept of the tectogene, that is, the great synclinal route that was thought to exist under trenches in accordance with the ideas of Vening Meinesz. In fact, rather than finding a route of 60-100 km beneath such trenches, the gravity anomalies are better explained by a thinning of the crust. Thus, trenches seem to be related to tension rather than to compression, so that they cannot be explained by the thrust of a drifting continent. The seismic belt along the middle of the Atlantic Ocean has been found to be associated with a median rift. The topographic profile of this rift, which lies along the axis of the Mid-Atlantic ridge, seems to be practically identical with those of the central African valleys. In fact, Heezen has traced this rift in a world-wide pattern, and one of the extensions includes the African rift valleys. Contemporary studies of the African rift valleys show that they have an origin in tensional forces. Thus, he believes that tensional forces also explain the median rift in the Atlantic. He points out that structural linearities in the Atlantic, not only of the Mid-Atlantic ridge but also of minor structures, are parallel to the continental margins, suggesting a deformation through extension of the suboceanic crust. All in all, he believes that the structures of the Atlantic and of other oceans as well must be explained by tensional forces. He concludes therefore, that continental drift according to the concept of Taylor is not correct since this would involve extension in the Atlantic, but compression in the Pacific. It seems necessary to believe that all ocean basins are undergoing extension. One way to accomplish this would be for the earth actually to be growing larger. Although he points out that this seems at first thought to be a fantastic idea, it might just be possible that the earth is undergoing some phase change whereby material of

the core of high density is being changed into mantle material of comparatively low density. If this happened, the needed expansion in the size of the earth might be effected.

Holtedahl, H., University of Bergen, "On the Geology and Morphology of Glaciated Continental Shelves": Following in the footsteps of his father, O. Holtedahl, H. Holtedahl for many years has extensively studied the continental shelf off Norway. In this communication he made a comparison of the Norwegian shelf with the glaciated shelves off the east and west coasts of North America which are remarkably similar geomorphologically. The continental shelf off a glaciated coast is characterized by a shallow fringe extending to a depth of about 50 meters and marked by numerous islands, skeries, and shoals. Off Norway this is known as the "strand flat" or skjaergaad, although glaciated coastlines are extremely irregular and deeply embayed by fjords. The margin of this strand flat is comparatively straight and is marked by a slope down of 150 meters or so. A broad and deep shelf, much deeper than found in non-glaciated areas, connects the strand flat with the continental slope. This deep terrace is marked by numerous shallow basins which sometimes line up along the shore side of the terrace to form a furrow or shallow linear depression; thus the deep terrace has a reverse slope. While Holtedahl believes that the strand flat is a highly glaciated area, he disagrees with many earlier writers who have supposed that the characteristics of the deep terrace are also ascribable to glaciation. It seems that only rarely have the fjords, and hence ice age glacial tongues, been extended on to the deep terrace. He believes that the slope between the strand flat and the deep terrace, along with the linear depressions at the base of this slope, are ascribable to faulting which began in the Tertiary and is still active. Continental segments have apparently been upraised along these fault lines rather than at the margin of the continental slope. He does not believe that the post-glacial isostatic recovery of Fennoscandia has much to do with this fault line. Although this post-glacial uplift has amounted to more than 100 meters in the central part of Fennoscandia, the uplift along the coastline of Norway has been comparatively small.

Houot, G., French Navy, "The Bathyscaph: An Exploration of Great Depth": This paper simply summarized the scientific results obtained by the FNRS-3 which to date has accomplished 56 dives. During the more recent descents, the French have succeeded in obtaining some remarkable photographs of the deep sea floor and of fish and other forms of marine life. Houot's paper was presented in his absence by another naval officer of the Groupe d'etude de la Recherche Sous-Marine in Toulon. (At the time of the meeting, Houot was en route to Japan to undertake a cooperative series of dives with the Japanese. It is proposed to make eleven dives off the east coast of Japan with Professor Pérès and with Japanese scientists as observers. The program is being financed by the Asahi Shimbum--the principal newspaper in Japan.)

Kuenen, Ph. H., University of Groningen, Netherlands, "The Age of a Mediterranean Basin". As a follow-up to his excellent work on turbidity currents, which has revolutionized concepts of marine sedimentation, Kuenen has recently devoted much attention to the reconstruction of ancient topography by determining the direction of ancient gravity-controlled turbidity currents. This direction of flow can apparently be readily determined for almost all turbidity current beds by any one of a number of microstructure criteria -- the most obvious of which is based on the asymmetry of current ripple marks. This paper considered the Cretaceous to the Oligocene paleogeography of southern France and northern Italy. There a study of turbidity current deposits in the Alpes maritimes shows that a high land mass must have existed on the site of the present Ligurian Sea. Pursuing this question further, Kuenen considered mechanisms whereby deep ocean basins might become continental highlands. He directed attention to the new explanation of Vening Meinesz (1958, in press) for the origin of deep basins such as the Gulf of Mexico and those of the East Indies. He suggests that crustal convection currents are directed downward beneath a deep, causing a rise of the level at which olivine is transformed into a denser phase. Strong positive gravity anomalies as are found in the Ligurian Basin might be ex-

plained in this manner. According to this concept, seismic observations should reveal a granitic layer beneath the Ligurian Sea.

Kuenen cautioned against full acceptance of the principle of permanence of the ocean basins most recently espoused by Ewing and Press (1956), who have stated that permanence is proved by the great geophysical (especially seismic) contrast between the continents and ocean basins. He pointed out that there is considerable geological evidence that continental areas have in fact been transformed to oceanic areas, and vice versa.

Landergren, S., University of Stockholm, "On the Distribution of Boron in Argillaceous Marine Sediments": This communication concerned the geochemistry of boron in marine sediments. Landergren pointed out first that the amount of boron in sea water is in direct relation to salinity, and for sea water of normal salinity the content is about 15 ppm of B_2O_3. He finds, however, that boron is greatly enriched in bottom sediments, having an average value of about 450 ppm in fine-grained sediments and about 60 ppm B_2O_3 in sandy sediments. He supposes that enrichment is due to surface adsorption on clays since the amount of boron is in relation to the surface area and surface activity of clays. Through a study of ancient sediments he finds that a high boron content is almost a certain indication of the marine origin of certain shales. The amount of boron in Cambrian sediments is essentially the same as that in Recent marine sediments from similar environments; hence, the geo-economy of boron has not changed since Precambrian times. He has made a study of some cores collected by the Albatross to determine the vertical distribution of boron and found some interesting variation, but the reasons involved are as yet too tentative to deserve discussion here.

Menard, H. W., Scripps Institution of Oceanography, "Distribution and Origin of Abyssal Smooth Regions": Menard pointed out that in the Pacific one is able to distinguish three types of low topographic relief: (1) extensive low hilly regions, (2) flat abyssal plains off continents, especially characteristic of the northeast Pacific, and (3) flat and gently sloping regions around Pacific island groups which he terms "archipelagic aprons." Similar topography exists in the other oceans. Menard believes that the initial topographic form of the sea floor must have been rough, so that smoothing requires extensive sedimentation or some other blanketing process. He considers that the smoothing of abyssal plains and continental rises has been accomplished by sedimentation from turbidity currents. He pointed out that these deposits are, in fact, dammed behind by physiographic barriers on the sea floor in such a way that they must be explained by the sediment being moved along the bottom from the continents rather than from pelagic sedimentation. Archipelagic aprons must have quite a different origin, however, since the islands are totally incapable of shedding the needed amount of sediment to build up these extensive forms. Menard therefore proposes that along with the development of the islands, which have grown from submarine volcanos, extensive fresh eruption of basalts occurred, and that the aprons are mainly composed of these flows which have drowned the initial irregular topography. Additional smoothing has subsequently taken place by sedimentation, but only a small amount has been required to smooth out the minor irregularities of great fissure eruptions. The amount of sea floor covered by archipelagic aprons is extremely extensive and roughly equals the extent of abyssal plains.

Menard stated that post-war expeditions of the Scripps Institution and the Navy Electronics Laboratory have covered more than the distance between the earth and the moon (240,000 miles). In spite of this, the Pacific is still relatively unknown, and when it is completely surveyed ten times as many seamounts as are now known will be discovered. From existing data he has computed in three different ways the probable number of seamounts more than half a mile high. He calculates that there are between 5,000 and 10,000 of these sea mounts in the Pacific.

Mosby, H., University of Bergen, "Renewal of the Deep Waters in the Norwegian Sea": Mosby considered the nature of the Norwegian Sea deep water which lies one or two hundred meters beneath the surfacial warm Gulf Stream water mass. These deep waters are characterized by

a very low and uniform salinity of 34.92 ppm and a low temperature decreasing toward -1° near the bottom. Mosby's principal conclusion was that about 14-1/2% of the water mass is renewed each year and that upwelling of the deep water mass owing to the production of new cold bottom water takes place at a rate of about 27 m of elevation per year.

Wiseman, J. D., British Museum of Natural History, "The Significance of Variations in the Rate of Accumulation of Globorotalia menardii d'Orbigny in a Core from the Equatorial Atlantic": Wiseman has adopted the approach of making a very careful and detailed study of a single core rather than a cursory examination of a great number of them. He discussed at length the problem of trying to be certain that a given core was both undisturbed through the technique of collecting and had accumulated in a place where sedimentation has been continuous and undisturbed by such things as bottom-dwelling organisms and turbidity currents. He pointed out that the core which he studied in detail was of such an undisturbed nature. Thus, he considered it useable for determining ancient temperature changes of the surface of the sea based upon the rate of accumulation of Globorotalia menardii menardii. Cores collected from the abyssal plains of the Atlantic were not use able because of the contamination introduced by turbidity currents, so that the core which he undertook to study was collected from a small rise out of reach of turbidity current deposits. The samples from this core conserve the evidence of two oscillations of temperature that can be directly correlated with climatic changes based upon radio-carbon dating on land. This was accomplished through the study of the rate of accumulation of G. menardii menardii. He finds that the rate of accumulation of $CaCO_3$ in the equatorial central Atlantic has been about 1 mg/cm^2/yr for the last 11,000 years. He also finds an especially warm period dated at about 3,000 B. C. which correlates with the Thermal Maximum; another warm period at about 9,200 B. C. which correlates rather well with the Allerőd/Two Creeks warm period; and a cool period at 9,750 B. C. which agrees very well with the cool Older Dryas. Another warm phase appears at about 10,250 B. C.

ADDITIONAL PAPERS PRESENTED AT THE COLLOQUIUM

Segre, A. G., Italian Geological Service, "Topographie et Géologie de la Mer Tyrrhénienne."

Muraour, P., Institute of Graduate Studies, Tunis, "Recherches Océanographique au large des Côtes de Tunisie."

Castany, G., Director, Geological Service, Tunis, "Etude Océanographique du Bassin Siculo-Tunisien."

Perrimont-Trouchet, M., Head Pharmacist-Chemist of the French Navy, "Possibilités Humaines de Pénétration Sous-Marine."

REVIEWS OF SOVIET PAPERS READ AT THE INTERNATIONAL ASSOCIATION OF PHYSICAL OCEANOGRAPHY

Toronto, September 1957

The Academy of Sciences of the USSR has published for its National Committee for Geodesy and Geophysics short reviews of articles presented by Soviet scientists at the September 1957 meetings of the International Association of Physical Oceanography held in Toronto during the XI General Assembly of the International Union of Geodesy and Geophysics. These are presented as follows:

V. G. Kort, NAVAL ANTARCTIC EXPEDITION OF THE USSR ACADEMY OF SCIENCES. The Soviet Antarctic Expedition was jointly sponsored by the USSR Academy of Sciences and the Central Office for the Arctic Sea Route. The aim of the expedition was to carry out research in the Antarctic in accordance with the program of the International Geophysical Year. The following main tasks were set before the expedition: Studies of the influence of the atmospheric processes in the Antarctic on the general circulation of the Earth's atmosphere, studies of peculiar geophysical phenomena, of currents in the Antarctic water and their relation to the general circulation of the Earth's oceans, and studies of the geological history of the continent.

To solve these problems the expedition carried out its scientific work on the Antarctic continent and in the surrounding waters.

Coordinated oceanographic work was conducted in the course of three months, from February 29 to June 8. During the whole navigating period from November 30, 1955 to July 5, 1956, (over seven months) the "Ob" covered 33,000 miles (scientific research was conducted along 20,000 miles). Oceanographic research was carried out along the coastal region of the Southern Antarctic from 91° to 162°. Oceanographic sections were made from the Balleny Islands to New Zealand across the Sea of Tasman, and from Australia to the Davis Sea.

From the Davis Sea the expedition accomplished a meridional oceanographic section across the entire Indian Ocean. Deep-water research was finished on June 8 near the mouth of Aden Bay. One hundred and fifty-six deep-water oceanographic stations were established.

Seven parties conducted coordinated oceanographic research on the "Ob" including: aerometeorological, hydrological, geophysical, hydrochemical, hydrographical, geological and biological research.

The most difficult and interesting part of the voyage was the route along the southern coasts of the Antarctic. The "Ob" followed the coast of the continent in the regions of the Knox Coast, the Sabrin Coast, the doubtful Discovery Land and the coasts of North Land and Clairie Land.

A detailed study of the region of Discovery Land showed that in reality it is either an island or a wide shoal covered with ice domes joined to the coast by the shelf ice.

The Antarctic expedition established 57 oceanographic stations in the coastal waters of the Antarctic.

Echo sounding measurements of the sea depth were done on a large scale. Navigators and hydrographers of the expedition checked the position of the coast along hundreds of miles. A number of astronomical points were determined in the almost unknown coastal regions to be used as survey geodesical bases in aerial photos. As a result of this work valuable data were collected concerning the almost unknown areas of the Antarctic coastal waters.

The sounding of the Davis Sea showed the presence of two ridges in the floor of the sea, separated by a chute between them. These ridges are obviously dumped moraines laying on the sea floor parallel to the ice barrier across the entire Davis Sea trending further towards Clairie Land (135°E). The northern edge of these dumps coincides in general with the position of the extreme edge of the shelf glaciers in the ocean. The formation of the outer dump evidently took place during the period of maximum glacier formation. The coastal moraine dumps correspond to the edges of the contemporary glaciers. The large number of sea floor samples containing rock fragments will allow determination of the geological structure of a large part of the coastal continent region, which is completely covered with ice and is inaccessible for ground investigation by geologists.

As a result the research work conducted by hydrochemists the following characteristics were defined for the given Antarctic region: the physical and chemical properties of the coastal waters and the stratification characteristics of the given region. Moreover, important data are accumulated on ice formation and on physical and chemical characteristics of the Antarctic sea ice and on regions of iceberg formation. For example, we may ascertain that the whole ice shelf of the investigated region in the Antarctic is the formation zone of Antarctic water.

Obviously the Antarctic waters could be formed anywhere in the presence a well-developed shelf and a moderate amount of advection heat.

The biologists of the expedition attained a view of the general characteristics of the animal and vegetable life in the areas investigated. They also collected many samples of the flora and fauna of the Antarctic.

Upon termination of work in the coastal waters the expedition conducted wide-scale oceanographic researches in the southwest part of the Pacific and Indian oceans. De-

tailed oceanographic records were made from the Balleny Islands to New Zealand across the central part of the Sea of Tasman, from Australia to the Antarctic coast and from the Davis Sea to the Kerguellen Islands. These records gave valuable data about the heat and water exchange between the Antarctic regions of the Indian and Pacific oceans.

The studies of the Kerguellen -- Gaussberg Threshhold showed that the existing conception of its morphological structure was erroneous. The geologists of the expedition accumulated valuable data about these sections. Numerous long cores were studied that threw light on the geological history of the ocean regions for hundreds of thousands of years. They managed to get, with the aid of a tubular piston, a core from the ocean floor of nearly 15 m. This is more than four times longer than any other core obtained from the Antarctic floor by previous expeditions.

A meridional oceanographic section across the Indian Ocean of nearly seven thousand miles in length and with 41 oceanographic stations was accomplished on the way from the Davis Sea to Aden Bay. The data collected along the route are of great scientific value. They show the zonal distribution of the physical and chemical characteristics of the Indian Ocean waters, and the boundaries of penetration of the Antarctic waters to the North.

Interesting information was obtained by meteorologists. Frequent radio soundings of the atmosphere were carried out up to the average heights of 18-20 km. The collected data supplemented by observations carried out simultaneously by meteorological stations situated on the same meridian further to the North on the Eurasian Continent, at Mirny and on the flow ice stations "North Pole" Numbers 4 and 5, will give exceptionally valuable information on the aerological structure of the lower layers of the atmosphere from the Antarctic to the central regions of the Arctic. This may permit the discovery of important laws of the interconnection of atmospheric circulation in the Northern and Southern Hemispheres.

Along the route across the Indian Ocean biologists have collected abundant material on the flora and fauna characterizing the zonal distribution of life in the ocean and the stage of penetration of the Antarctic forms of life to the North.

The works of the sea party of the complex Antarctic expedition during 1956-1957 include the investigation of the western part of the Indian sector of the Antarctic waters.

Five oceanographic meridional sections on board the d/s "Lena" will be done from the Antarctic sea coast to 55° S, en route from Mirny to Princess Ragnhild Land.

The main task of these investigations is the study of the hydrology of the almost unexplored shelf zone. In the same region the hydrographical party of the expedition on board the "Lena" will make systematic investigations of the coastal zone by serial photographic survey and deep soundings.

G. B. Udintsev, A. P. Lisitsyn, PROBLEMS OF THE GEOLOGICAL STRUCTURE OF THE NORTH-WESTERN PACIFIC AS RESULT OF NEW DATA ON THE FLOOR RELIEF AND DEPTH OF LOOSE DEPOSITIONS. 1. Till recently the Northwestern Pacific remained little known. Data on the geological structure has been presented by Japanese hydrographers and by a few oceanographic expeditions only. Later, the American Scripps expedition "Transpac" added a little to this information. A great number of geological investigations were carried out by the Soviet expedition on board the "Vityaz" during 1949-1955.

Investigations of the oceanic floor carried out by the Soviet expedition led to a discovery and the study of many large forms of relief little known before. A great variety of small forms of submarine relief was studied as well. The investigations of the depth of loose deposition were performed by means of experimental seismology. Two profiles north-west of the Kurilo-Kamchatka trough and one through the Philippine basin were made.

2. The relief of the continental bank within the area investigated by the "Vityaz" is relatively simple. The bank dimensions vary depending on whether it is the area of the continent or the surface of the continental slope. The submerged plains of the

continents are characterized by a more complicated relief of small shapes, in particular, by submerged erosion valleys. The continental slope represents a complicated transitional zone. Within this zone there are systems of island ridges, peninsulas and submarine mountain chains which separate the troughs of the outlying seas. The bottoms of the troughs and some hills form the steps of the continental slope divided by steep shelves. Large forms in the transitional zone are, as a rule, a continuation of the large forms of continental and island land or, having common strikes, adjoin them.

The continental slope is separated from the floor of the Pacific by a belt of deep-water troughs. The Aleutian trough adjoins the Kurilo-Kamchatka trough, the Kurilo-Kamchatka adjoins the Japanese trough and the Japanese adjoins the Indsu-Bonin trough. A rather high ridge is found only between the Indsu-Bonin and Marianas troughs. The Ryukyu trough stands apart.

Massive swells discovered on the edge of the oceanic floor extend along the deep-water troughs and terminate in large hills in the corners of the ocean bed. Hilly plains divided by zones of mountainous relief of volcanic origin and the mountain ridges are most typical of the relief of the oceanic floor. There are no suspension flow beds on the surface of these plains. It is found that the trough of the Northwestern Pacific is limited by the northern extension of the submarine Hawaiian ridge in the East, whereas in the South it is limited by the western termination of the central part of the Pacific swell. A zone of large tectonic deformations stretching Northeast is found in the central part of the trough. This zone is similar to the fault zones of the eastern part of the ocean. Lying in the boundaries of the ocean the Indsu-Bonin island ridge and the deep-water trough differ greatly by the character of their relief from the island ridge of the continental slope and the adjoining troughs. The Philippine trough, separated by the Indsu-Bonin ridge, is different from the floor of the northwestern trough of the Pacific because of the character of the submarine relief.

3. The comparison of the submarine relief with the geological structure of the continental and the island land leads to the conclusion that a weak morphological connection of the land tectonics and relief of the continental bank exists, and contrary to that, that there is a close connection between the land tectonics and the relief of the continental slope. The belt of deep-water troughs limits the extension of all large forms and, apparently, structures of the continental slope. The western of Honshu Island adjoining the Indsu-Bonin ridge, is an exception. At the same time the coincidence in direction of the northern part of the submarine Hawaiian ridge and the submarine Shirshov ridge in the Bering Sea and the extension of the Indsu-Bonin Island ridge in the region of Honshu and Hokaido and Sakhalin permit the supposition that the existence of the largest tectonic meridional lines exist here for the floor of the ocean and for the continental slope as well. The direction of the tectonic deformation zone discovered in the central part of the north-western trough of the Pacific, as well as the direction of the belt of deep water troughs and adjacent island ridges from one side and swells from the other, coincides with the stretch lines according to the hypothesis of convection currents.

4. The results of seismic soundings in the North Western Pacific trough give evidence about the existence of some discontinuities under the floor surface. An extremely sharp reflection from one of these boundaries permits the assumption that it is a crystalline foundation. The depth of the loose depositions increases to 600 m in the central part of the trough from 150-200 m along the edges and the outcrops of the basic rocks at some outlying elevations. The thickness of the layers of the depositions increases in the central part of the trough too. The deflection of the central part compensated apparently by accumulation of the sedimentary thickness. The depth of the loose depositions on the floor of the Philippine trough varies extremely, testifying to the fact that the hollows between the elevations of the floor are being filled up.

V. Kh. Buinitsky, FORMATION AND DRIFT OF ICE COVER IN THE ARCTIC BASIN. 1. Drift of the sea ice in the Arctic basin is caused by a joint effect of wind and permanent current.

2. The permanent current is very

homogeneous in space and stable in time and in its nature is a run-off of cold surface waters which is a result of an influx of the Atlantic, Pacific and river waters into the Arctic basin.

3. Drift of ice at the sea for relatively short periods of time and within a small region mainly occurs due to the wind. A barometric system passing over a given locality determines the direction of ice movement; clockwise or counter clockwise and along some orbits (the direction of which in many cases coincides with that of isobars. Besides, ice experiences constant rotation.

4. A general drift of the sea ice in the Arctic basin connected with its carrying out into the Greenland Sea is caused by a constant run-off of the surface waters. Together with the latter, ice is flowing into the strait between Greenland and Spitzbergen along the shortest trajectory, similar to arcs of large circles.

5. Out of the whole amount of energy brought on to the ice cover by the wind only 15-20 per cent carries the ice out of the Arctic basin. The rest (80-85 per cent) being spent to deform the ice cover and cause local movements of some ice fields.

6. These displacements of ice lead either to splitting of ice, or to ice compression and jamming. Ice movement is not casual but is the normal state of the ice cover.

7. Another no less important law of the ice formation in the Arctic basin is the levelling process of its surface and thickness. It was established that winter freezing, summer thawing and freezing, isostatic movement, ice freezing in autumn, mechanical destruction of ice under the effect of wind and transference of destruction products, ice evaporation, gradual break-up of submarine blocks, etc., lead to the erosion of either the lower ice surface, or the upper, or both at the same time.

8. Results of these laws contradict each other. The movements lead to destruction and break-up of the ice cover. The levelling processes makes the surface more smooth, thickness more even, and increases stability. In the course of the process the effect of these movements decreases giving place to the levelling which becomes of major importance.

9. As a result of ice movements, on the one hand, levelling processes, on the other, internal structure and physical and chemical properties of ice gradually change, which brings about the formation of the Arctic ice-pack, i. e. a perennial ice, much transformed due to outer factors and typical of the central areas of the Arctic basin.

M. N. Koshliakov, SOME PROBLEMS OF GENERAL OCEANIC CIRCULATION. 1. The problem of general circulation in oceans is the central problem of modern physical oceanography. Theoretical considerations are the main instrument for gaining an insight into the essential characteristics of the deep currents system in the ocean.

2. General circulation of the ocean is interpreted as the mean average system of currents, approximately corresponding to the mean annual scheme of circulation. From this aspect all circulations of lesser scales should be considered as turbulence.

3. In the ocean, in contrast to the atmosphere, all the factors which generate movement (wind, thermal irregularity) exert their influence solely from the surface of the ocean. The surface and deep water currents are included in a single circulation system having horizontal and vertical components.

4. Convection currents in the ocean have small velocities, are mostly zonal (they are directed eastwards in both hemispheres), and concentrate in a layer, the thickness of which is limited by the depth of winter convection or wind-generated mixing. Estimates of the velocity of convection currents for the tropical part of the North Pacific give values not exceeding 3-4 cm/sec. at the surface.

5. Wind is the main cause of currents in the ocean, especially in the deeper layers where the gradient component of wind currents prevail. In the depths of the ocean (with the possible exception of the move- of Antarctic bottom waters) no currents exist that are not controlled by the field of

wind stress over the ocean. Thus, for instance, no currents can develop analogous to some intermediate intruding streams (Defent, 1936), and there can exist no intermediate surfaces of no motion.

6. A computation of mass transport of wind currents in the North Pacific, based on the theory of Stockman - Munk, has given values which are in fair agreement with a maximum sinking of the surface of no motion.

7. Horizontal circulation prevalent in oceans can be, in a most general manner, fairly well described by geostrophic models. In contrast to the atmosphere, the ocean is characterized by a similarity of the geostrophic system at all depths.

Computations of the geostrophic current in the northwestern part of the Pacific, based on data obtained by the Mansyu and the Vityaz, give similar circulations at all levels including surface and intermediate waters.

8. The presence of elements of vertical circulation and the corresponding turning of the currents' velocity vector with depth are determined by the effect of frictional forces. Zones of stable winds are characterized by the following scheme: transverse (in respect to the geostrophic current) velocities and divergence of pure drift currents in the surface layers of the ocean are compensated by transverse velocities and divergence of an opposite sign due to horizontal friction in the gradient current in the deeper layers. Computation carried out for several regions of the North Pacific confirm this scheme.

9. Zones of convergence of average currents in regions of polar and subpolar fronts, related to vertical circulations of an oceanic scale, may be explained in a most general way by an intensive horizontal exchange of momentum (turbulent friction) in the field of a gradient wind-current. An approximate calculation of transverse and vertical velocity components in the region of the Kuro-Shio front shows that on a horizontal plans the current deviates but little from the geostrophic direction (by an angle of no more than 10^{o}).

10. A conjunction of the scheme of wind-generated circulation and the climatic processes forming the thermohaline structure of the surface waters of the ocean permits an explanation of the complex vertical structure of oceanic waters, owing to the presence of elements of vertical circulation; in particular it accounts for the tongue-like character of isoclines of the essential oceanographic elements on meridional sections.

Another most important factor in the formation of the structure of oceanic waters is the process of horizontal turbulent mixing which is directly related to the phenomenon of convergence in the field of the mean current indicated above. This process, though important over the whole of the ocean, is especially intensive in the frontal zones.

The model described above permits explanation of the vertical structure of ocean waters still retaining the similarity of horizontal circulation at all depths, and without recourse to some hypothetical stratified system of currents.

11. This model explains the presence in the central parts of the oceans of intermediate antarctic and subarctic waters, as well as, for instance, the phenomenon by which the deep waters from the northernmost regions of the Atlantic "leak" into the North Atlantic current.

12. A definite relationship exists in the Atlantic between the wind field and the coast-line configuration, which determines the northern half of the ocean. The movement of deep waters in the opposite direction is regarded as a compensation of this transport.

13. The highly complex system of currents in the Atlantic ocean can be represented in a most general manner by a single circulation which combines the known horizontal eddies in both parts of the ocean with the vertical circulation described above. The latter is especially important in the equatorial region of the ocean. Here the current differs greatly from the geostrophic, the velocity vector being gradually involved in a rotational movement with depth.

There is an opinion that the dyamic method cannot be successfully applied to the study of currents in the Central and

Southern Atlantic owing to the strong deviations of the current from the geostrophice regime and the insufficient precision of the determinations of the structure of the deep-water layers.

14. In the Pacific and Antarctic oceans the elements of vertical circulation are far more feebly expressed than in the Atlantic and the currents system is in general similar on all horizons. Only the Antarctic bottom waters are an exception, their dynamics being determined by the complex relief of the ocean floor and the bottom-friction.

15. Some of the prevalent conceptions of the structure of deep currents in the oceans, particularly, the Wust-Defant schemes of deep circulation in the Atlantic and the methods used by these authors, are incorrect or questionable in many aspects from the standpoint of modern physical conceptions of the dynamics of the ocean waters. Thus:

(a) Wust and Defant's conception of the deep currents in the Atlantic as a stratified system of prevailingly meridional currents not connected directly with the surface circulation is incorrect. Such a scheme could not be, for instance, accounted for by thermo-dynamic factors.

(b) The core method of Wust (Kernschichtmethode) consists of an examination of the tongue-like bends of isoclines of the content of definite waters on certain surfaces selected by the authors. As an approach to the study of the average transport in the ocean this method is too uncertain and not justified physically. Furthermore the surfaces of extreme salt or oxygen contents with which Wust is operating are not the surfaces of streams.

(c) The Defant method of the selection of an intermediate surface of no motion for dynamic computation is not warranted physically. Nor is the scheme of currents in the Atlantic (based on Defant's surface of no motion) obtained by Defant (1941) and Wust (1955) justifiable by any physical considerations. The recent computations of Wust give currents in the surface horizons which do not agree with the well-known scheme of surface circulation in the Atlantic. This makes questionable the results of the computations for all depths. The arbitrary selection of the surface of no motion is the cause of the velocities of bottom currents obtained by Wust.

INVESTIGATION AND CONSERVATION OF MINERAL RESOURCES[1]

Moscow, January 1958

The Sixth Five-Year Plan (Ed. note: The Sixth Five-Year Plan began in 1956 and will end in 1960.) instructed that these mineral investigations should focus on the most important deposits; reserves of iron and nickel ores were to be expanded by 30 to 50 per cent beyond those existing at the beginning of the five-year period; copper, bauxite, titanium, phosphate and borax by 40 to 50 per cent; niobium 50 to 55 per cent; mercury 75 to 80 per cent; and petroleum 65 to 70 per cent. An extension of the explorations for coal is envisaged with a 35 to 40 per cent increase for the industrial coals and 40 per cent or less for coking coals.

From a knowledge of the mineral resources of the Soviet Union it is easy to realize the amount of geologic work and intensification of physical effort needed to assure a practical solution to the problems posed by the decisions of the 20th Congress.

The extension of mineral reserves, indispensable to meet the constant needs of industry and for the creation of stocks of raw materials, demands research principally in the eastern regions of our country, as the Sixth Five-Year Plan foresaw. In these regions the geologists will have to devote their major effort to discovery and study of reserves of petroleum and exploitable natural gas, great reserves of industrial coal and coke, and also iron ores which can be smelted at low temperatures. Moreover, it will be necessary to discover beds of manganese which will

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serve in the manufacture of ferromanganese in the industries which will be constructed in the east of the country, likewise for the entire gamut of rare and widely dispersed elements so necessary for the development of the great branches of the national economy.

During the preceding two years of the Sixth Five-Year Plan the geologists of the USSR achieved important successes.

In different regions of the Soviet Union and particularly in the eastern region, numerous deposits were discovered. These mineral raw materials are of capital importance for the national economy and lead to a notable extension of the known reserves of all mineral wealth.

An excellent example is provided by the diamantiferous deposits of Yakutia. (Ed. note: Yakut Assr, Capital Yakutsk, 65°0' N 130°0' E, six major diamond areas are noted in Western Yakutia: The Malaya Botuobuya, The Daldyn-Alakit, The Middle Markha, The Tyung, The Muna, and the Northern Olenek. In the course of these last years, in regions where only isolated discoveries had previously been made, great diamond-bearing provinces have been blocked out, with underground and superficial deposits of a quality and richness equal to the best deposits in the world. We are able to affirm with certainty that the diamond reserves of the USSR occupy one of the first places of the world and their discoverers have received the title of the laureates of the Lenin prize: geologists A. P. Burov, G. K. Jukerevich, G. K. Fienstein, V. B. Belov, B. M. Shusukin, and J. I. Khabardin.

In the near future the exploitation of these diamond deposits of Yakutia will be begun, meeting the needs of the national economy in diamonds.

In the course of the year 1956 to 1957, geologists have undertaken a grand synthesis of the information obtained during the prospecting for coal deposits. They have calculated, according to the international rules, that the coal reserves known in the USSR as of the first of January 1957 are the world's most important, in excess of 8,699 billion tons, or 57% of the world's reserves.

During these last years not only important beds have been discovered, but also new coal basins. The coal basin of eastern Yakutia is in this last category, with reserves estimated at 40 billion tons, of which the great part can be exploited by open pit mining, coking coal of excellent quality is present. The discovery of iron ore in immediate proximity to the coal district is of great industrial interest.

The exploration during the first years of the Sixth Five-Year Plan showed that the isolated deposits of tin found in Primorye (45°5' N 135°0' E) in 1954 are part of a stanniferous province containing great reserves of tin and are considered to be a first order base for the industrial exploitation of tin. The results of prospecting of these tin beds of Primorye have a major importance for the national economy because until now only the regions of the northeast of the USSR were considered to be stanniferous provinces capable of yielding high-grade ores.

In the territory of the province of Magadan, (59°6' N 150°8' E) which extends from the limits of Yakutia to the edges of the Bering Sea and the Arctic Ocean, geologists have discovered and prospected new auriferous outcrops which present notable possibilities.

The iron-bearing district of Belgorod-Obojan (50°36' N, 36°35' E) discovered in 1954 through the efforts of the Belgorod expedition is reputed to be the most important iron deposit of the world; its ores are distinguished by their excellent quality. Instead of the 300 million tons of iron ore foreseen by the plan of 1956 we have discovered 700 million tons, and the estimation of reserves in the geologic report of the expedition offers great promise. Concurrent with the prospection for iron ores in the basin of Belgorod-Obojan, the hydrogeology of the deposits was studied, and the reserves of subterranean water estimated. These studies have demonstrated that the iron ores of Belgorod can be exploited despite their apparently large water-content.

The results of the study of the titaniferous zinc deposits of Samotkansk (in the Ukraine), discovered in 1955, show that they alone would suffice to meet the indus-

trial needs of the USSR during a long period. In 1956 and 1957 additional titaniferous deposits were discovered in the Ukraine.

During the two last years of the Sixth Five-Year plan important work has also led to the discovery in the eastern regions of the USSR of a variety of other mineral wealth.

The discoveries in the region of Chitan ($54^{o}0'$ N $116^{o}0'$ E) of a net of molybdenum veins and of an enormous copper deposit were evaluated in a preliminary way and seem to exceed all other deposits of the country.

The reserves of sillimanite found in the autonomous Republic of Mongolia-Buryat (54^{o} $0'$ N $111^{o}0'$ E) are also very important. The great hydrodynamic possibilities of the Angara River might lead to the creation of a local aluminum industry.

The geologists of the Geological Service of Irkutsk, who attach great importance to the creation of precious metals reserves, intensified their prospecting efforts in 1957 and soon discovered rich resources of precious metals in Sayjan ($53^{o}30'$ N $95^{o}0'$ E). The provinces of Chitan, of Khabarovsk ($48^{o}30'$ N $135^{o}0'$ E) and others also contain precious metals.

It is important to emphasize that the prospecting work carried on during 1956 and 1957 has led to positive results in all regions of our vast country, and that mineral resources have been discovered throughout the territory of the USSR.

The geologists of the State Geological Survey Service of Georgia discovered interesting possibilities in manganese under new geologic conditions and this suggests that Georgia possesses important deposits of manganese.

In 1957 the geologists of Armenia discovered iron deposits of particular importance for Transcaucasia, and the remarkable success in the domain of gold prospecting supports the hope that in the near future Armenia will occupy a high place among the auriferous regions of the country.

In 1957 interesting new copper deposits were discovered in Kazakhstan. These deposits occupy important areas in association with mercury, bauxite, and lead zinc minerals; the reserves of molybdenum have also been notably increased. In Kirgizin a series of new beds of mercury were identified. The possibilities of exploitation are reported to be far better than had been believed at first. We have every reason to believe that the possibilities of Kirgizin are sufficiently great to satisfy and even to surpass the national demand for mercury.

In carrying out the decisions of the 20th Congress of the Party our geologists effected investigations on a grand scale in the east of the Soviet Union for oil and gas. Natural gas was discovered in 1957 in Yakutia, in the Mesozoic deposits of the Lena Basin. A second deposit was found in the Cambrian of the province of Irkutsk. These discoveries confirm the new hypothesis of our geologists that oil exists in the eastern regions of the country.

The geologists of Kazakhstan, who attach much importance to research on oil and natural gas, have obtained particularly encouraging results in the region of the Ili River (Ed. note: Flows into the SE end of Lake Balkhash Kazakh SSR $45^{o}4'$ N, $74^{o}1'$ E) and of the Turgay folding. The possibility of still more discoveries of oil and gas in Kazakhstan is not excluded.

The research in exploration carried out in the petroliferous districts of the Bukhara-Khiva ($39^{o}50'$ N $64^{o}15'$ E)depression has lead to the discovery of natural gas in Uzbekistan and to the supposition that other new deposits exist.

Thanks to their important exploration and research the geologists of Turkmenia have demonstrated numerous structures favorable to the existence of oil and gas which will be studied in detail in 1958.

In the Sarmatian (Upper Miocene) of Moldavia the first deposits of oil were discovered in 1957.

However, the success achieved during the last two years of the Sixth Five-Year Plan has not let to a slackening of effort. It is indispensable, in fact, to emphasize that the importance of the problems which should be solved by geologists grows as a

function of the development foreseen for the national economy during the fifteen years to follow. N. S. Kruschev, at the Jubilee Session of the Supreme Soviet of the USSR emphasized the great possibilities of industrial development of the USSR.

According to his remarks, in the course of the fifteen years to come, the annual production of the principal industries, such as that of cast iron, should reach 75 to 80 million tons. The manufacture of steel will be from 110 to 120 million tons, the production of oil 350 to 400 million tons, of natural combustible gas 270 to 320 billion cubic meters, of coal 650 to 750 million tons, the manufacture of cement 90 to 110 million tons.

Very soon great and rich metalliferous mineral deposits must be discovered and studied, and likewise for reserves of oil, of coking coal, of diverse non-metallic industrial minerals, and of raw materials for fertilizer.

In prospecting for such reserves geological investigations acquire a particular importance; they insure continuing discovery of new reserves.

One should recall that the industry of the U. S. A.,which produced 94.6 million tons (Ed. note. Metric tons. The United States Bureau of Mines calculates that 1 metric ton is equal to 7.266 barrels on the average.) of oil in 1924 only attained a production of 352.6 million tons of oil in 1956. Thus it required thirty-two years for America to quadruple its production. In the USSR we should augment our production four times in fifteen years. It is then evident that the Soviet geologists must make an important and sustained effort to assure to industry the reserves necessary for the realization of its plan. To assure the present level of their production the U. S. A. drills 210 million feet annually for exploration and information while the USSR drills only 16 million feet a year. It is evident that to attain such a production of oil it will be necessary not only to augment the number of borings, but also to have a great knowledge of the terrain explored and to employ the most rational method of research and exploration.

To attain such an extension of the petroleum reserves it is necessary to modify fundamentally the present methods of exploration and research. In the first place regional geologic studies should be developed and indispensable geophysical methods of exploration be utilized. These will permit the rapid localization of different petroliferous structures and even of entire provinces, which will be then the object of intense geological exploration. That is why it is necessary to delimit as quickly as possible the areas of extension of structures and of newly discovered provinces to determine their geology and finally to proceed with exploratory drilling in order to prepare these deposits for industrial exploitation. Geologists will not be able to quickly resolve such detailed problems except by judiciously choosing districts to study where an absolute minimum of borings will be authorized. All available information must be gathered to obtain maximum results.

As a result of the geological and geophysical works carried out in the lower basin of western Siberia an accumulation of gas has been discovered in Berekov, and, additional structures likely to enclose oil and gas have been discovered. Unfortunately, many of the explorations were carried out only to shallow depth. Thus for example a series of tests for petroleum and gas were abandoned before attaining the depth which had been proposed; the drilling was stopped in the Permian when it should have continued to the Carboniferous. The results of such work do not permit the drawing of certain conclusions and the only thing to do is to continue the drilling. Geologists have less and less time to resolve the existing problems and it is indispenable for them to utilize whatever time they have in a particularly economical and wise manner.

In our opinion there are in the eastern regions of the USSR numerous districts having oil and gas possibilities which should be studied with care. Outside of Yakutia, the province of Irkutsk, ($52^{\circ}30'$N $104^{\circ}20'$ E),the region of Krasnoyarsk (56° $10'$N 93° E), the province of Kemerovo ($55^{\circ}4'$ E $86^{\circ}1'$ N), and all of the lower region of western Siberia, the folds of Turgai and the Caspian depression merit serious study for their petroleum possibilities. These regions are of great geo-

logic interest, but unfortunately, the work of petroleum exploration has degenerated to an inadmissibly slow pace.

In recent years failure to develop new methods and equipment for research has led to increasing inefficiency. All our facilities should be used to the maximum in the course of geological research. Because of insufficient geological training, technical background, and the imperfections of previous work in petroleum prospecting, it is indispensable to carry out new researches in the regions previously studied and in particular in the lower regions of western Siberia, in Armenia, in Georgia, in Moldavia, etc.

Geologists know well that a detailed study of the structure of the deep formations, the tectonics, the stratigraphy, and the systematic development of a region necessitate coordinated geological and geophysical work. This is confirmed by the practical results obtained from petroleum explorations in France, western Germany, Italy, and the desert regions of the Sahara. That is why the intensification of the exploration work is possible only when applying geological and geophysical methods simultaneously.

Following the example of foreign countries it is necessary to study basins and folds found under thick series of sedimentary formations by combined methods of exploration. Such methods will surely lead to important scientific and practical results. In 1957, in the provinces of Tomak and Ornsk, combined research methods led to the discovery of sedimentary iron ores extending over a vast surface containing probably dozens of billions of tons. It is interesting to recall that beds of titanium and of zinc have been found in these same regions. The results obtained indicate that the lower region of western Siberia possesses not only deposits of oil and gas, but also other important mineral deposits such as titanium, zirconium, native sulpher, alkaline salts, phosphate, etc.

Because of the rapid expansion of industry and the abrupt development of agriculture the study of ground water resources is particularly important, for their consumption grows from year to year. Hydrogeologic studies have caused the recognition of numerous regions containing deep water in Kyzyl-Kum, Kara-Kum, the peninsula of Mangyshlak, the Caspian depression, Transcaucasia, the depression of Kura-Araks ($41^{\circ}20'$ N $45^{\circ}40'$ E), and other deserted and semi-deserted regions until now considered as lacking in water resources. It is important to note that in addition to water usable only industrially, there also exists potable water. The development of industry and of agriculture in these regions need not be limited any more by the lack of industrial and potable water.

Water reserves have been found also in prairie regions, the Black Earth Belt of the northern Caucasus, Kazakhstan, Kirgizia, and in other regions of the country. It is essential to organize a rational utilization of ground waters in order to conserve them and prevent their pollution so as not to cause irreparable damage to the national agriculture. Very likely it will be necessary to create hydrogologic and geologic organizations which will have the function of discovering, exploiting, and preserving water resources.

It is also necessary to intensify our studies of the mineral fertilizers: apatite, phosphate, alkaline salts, chalk, etc. The Soviet Union actually possesses arable lands such as do not exist in any other country of the world. We are already exploiting tens of millions of hectares of diverse lands. The problem consists in assuring to agriculture a sufficient quantity of mineral fertilizers. Geologists should search for beds of mineral fertilizer in the agricultural regions themselves to avoid transportation to great distances. In the USSR numerous deposits of mineral fertilizer have been found but their geographic situation has not always been favorable. It is an important and honorable task for the geologist to correct this geographic distribution of fertilizer.

As was decided at the February Plenary Session of the Communist Party the various geological services of the USSR are now reorganized and organically separated from industry and construction. Now the work of geologic study, research, and exploration for mineral wealth is the responsibility of a single organization: The Minis-

ry of Geology and Conservation of Mineral Resources of the USSR. The advantages of such an organization are unquestionable for they assure highly qualified direction of the work of exploration and suppress interpro fessional barriers and duplication of effort.

The unification of the geological ser vices will permit the carrying out of geologic investigations step by step according to a single, scientifically established plan of study, and will certainly lead the Soviet geologists to practical results in the near future. The work of exploration will develop according to scientifically established principles. The geologic cartography will be developed to begin with,corresponding with the development of the combined resources of the entire USSR. This unification of the geological services of the USSR has already given positive results, but there is much more to do. Numerous establishments and geological organizations still remain isolated. It is necessary immediately to organize the geological services according to the functions appropriate to each territory and according to the difficulty of the study of the natural wealth of each region of the USSR.

Until now the exploration for many minerals remains insufficient and the results are sometimes deficient because of the incomplete study of methods of research applying to this or that mineral, or the lack of knowledge of the geological character of the region.

The efficacy of exploration and geological research will increase principally as a result of more complete study of the geologic structure of the regions considered. It is therefore indispensable to give greater emphasis to the geologic and hydrologic cartography of the USSR with the constant assistance of geophysics. This will assure a solid base to all future exploration work and researches and will guarantee their success.

Simultaneously it is essential to improve geological training, prospecting, and research by applying modern methods and techniques, and by the invention of new methods and apparatus. Despite improved techniques the technical facilities of the geological service include much outmoded apparatus. Necessary additions to our exploration facilities are: (1) large quantities of new drilling apparatus, (2) development of high production drilling gear for obtaining information borings to 2,000 meters or more, (3) development and application of light drilling apparatus for information purposes and the mechanization of exploration work, (4) application of the technology of exploration drilling for information, the perfection of existing apparatus and methods of geophysics, etc. (5) development of percussion apparatus for drilling information cores of small diameter, and research into more efficient methods of drilling such as ultrasonic, explosive, etc., and (6) the creation of geophysical equipment of high competency and performance.

Without any doubt the Soviet geologists will brilliantly resolve the complicated and delicate problems entrusted to them. The development of industry and agriculture will not be limited by the exhaustion of reserves.